

ESTCP Cost and Performance Report

(EW-201344)



High Efficiency Dehumidification System

August 2018

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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) 8/6/2018		2. REPORT TYPE ESTCP Cost & Performance Report		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE High Efficiency Dehumidification System, Cost and Performance Report				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT	
6. AUTHOR(S) Scot M. Duncan and Dahtzen Chu				5d. PROJECT NUMBER ESTCP	
				5e. TASK NUMBER EW-201344	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army Engineer Research and Development Center (ERDC) Construction Engineering Research Laboratory (CERL) PO Box 9005 Champaign, IL 61826-9005				8. PERFORMING ORGANIZATION REPORT NUMBER EW-201344	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Environmental Security Technology Certification Program 4800 Mark Center Drive, Suite 17D08 Alexandria, VA 22350-3605				10. SPONSOR/MONITOR'S ACRONYM(S) ESTCP	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) EW-201344	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The current "industry standard" method to control relative humidity (RH) and biological growth involves sub-cooling air to condense moisture out of the air, then reheating the same air that was just subcooled to reduce the RH of the air before it enters the space. However, the heating, ventilating, and air-conditioning (HVAC) systems at many Federal facilities are not equipped with (or do not use) the required reheat function, so high indoor RH and the growth of mold are often inevitable occurrences. The High Efficiency Dehumidification System (HEDS) is a patent-protected, proprietary energy recovery method designed to save more than 50% of the dehumidification-related cooling and heating plant energy in RH controlled environments. This report evaluates the cost and performance of the HEDS technology. Performance claims, installation costs, and maintenance impacts were investigated through the installation of two test units at Tinker Air Force Base, OK and Fort Bragg, NC. Results indicate that HEDS significantly exceeded the energy savings targets. This investigation concludes that, since HEDS uses reclaimed energy for the reheat energy source, it offers a cost-effective solution to provide American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 90.1 compliance across a wide range of HVAC system sizes and types.					
15. SUBJECT TERMS Buildings, Molds (Fungi)—Control, Sick-building syndrome, Dampness in buildings, Humidity—Control, Cost and Performance					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 66	19a. NAME OF RESPONSIBLE PERSON Dahtzen Chu
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code) 217-373-6784

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COST & PERFORMANCE REPORT

Project: EW-201344

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ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AHU	Air-Handling Unit
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BAS	Building Automation System
BEV	Belimo Energy Valve
BOMA	Building Owners and Managers Association International
BTU	British Thermal Unit
BTUH	British Thermal Unit per Hour
CAV	Constant Air Volume
CC	Cooling Coil
CERL	Construction Engineering Research Laboratory
CFM	Cubic Feet per Minute
CHW	Chilled Water
CHWRT	Chilled Water Return Temperature
CHWST	Chilled Water Supply Temperature
CMVP	Certified Measurement and Verification Professional
CRC	Cooling Recovery Coil
CV	Control Valve
DFAC	Dining Facility
DOAS	Dedicated Outdoor Air Supply
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DX	Direct Expansion
EO	Executive Order
ESTCP	Environmental Security Technology Certification Program
EUI	Energy Use Intensity
EUL	End of Useful Life
EW	Energy and Water
°F	Fahrenheit
FCU	Fan-Coil Unit
GHG	Greenhouse Gas
GPM	Gallons per Minute
GSA	General Services Administration
HAI	Healthcare Acquired Infection
HEDS	High Efficiency Dehumidification System

HEDS-VAV	High Efficiency Dehumidification System-Variable Air Volume
HP	horsepower
HVAC	Heating, Ventilating, and Air-Conditioning
ICC	International Code Council
IECC	International Energy Conservation Code
IEEE	Institute of Electrical and Electronics Engineers
IMC	International Mechanical Code
IPC	International Plumbing Code
kW	Kilowatt
LEED	Leadership in Energy and Environmental Design
MMBTU	million BTU
MOU	Memorandum of Understanding
NDAA	National Defense Authorization Act
NG	Natural Gas
POC	Point of Contact
PTAC	Packaged Terminal Air Conditioner
RH	Relative Humidity
RHC	Reheat Coil
ROI	Return on Investment
RTU	Roof Top Unit
SAT	Supply Air Temp
SIR	Savings to Investment Ratio
TD	Temperature Drop
Temp	Temperature
UFC	Unified Facilities Criteria
USACE	U.S. Army Corps of Engineers
VAV	Variable Air Volume
VFD	Variable Frequency Drive

ACKNOWLEDGEMENTS

Thanks are owed to Mr. Timothy Tetreault and the entire Environmental Security Technology Certification Program (ESTCP) team that took a chance by providing a small team of engineers the opportunity to build and test the High Efficiency Dehumidification System (HEDS). Without their foresight and the excellent comments from the peer review team, getting test units built, installed, and tested would likely not have happened this soon.

Mr. Curt Phillips, CEM, CMVP, Resource Efficiency Manager at Fort Bragg NC and Mr. Joey Hunter, Mechanical Engineer at Tinker Air Force Base (AFB), OK were instrumental in making those tests successful. There were significant challenges in getting the chiller plants running, and keeping them running, and we know that they spent significant amounts of time staying on top of the mechanics to ensure that the best possible outcomes occurred. We know that this was unbudgeted time, and truly appreciate the “over and above the call of duty” efforts that they both expended.

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EXECUTIVE SUMMARY

Proper relative humidity (RH) control is critical to maintaining healthy and productive indoor environments in buildings. It is estimated that U.S. companies waste as much as \$48 billion annually covering medical costs and \$160 billion annually in lost productivity as a result of sick-building syndrome (Mumma, 2006). Mold remediation costs associated with poor RH control have been observed to top \$1 million annually on military bases. Proper RH control minimizes the potential for indoor air quality problems and related sick-building illnesses while improving thermal comfort and productivity.

The current “industry standard” method to control RH and biological growth involves sub-cooling air to condense moisture out of the air, then reheating the same air that was just subcooled to reduce the RH of the air before it enters the space. This method has been around and used for over 100 years and is known to be very energy intensive due to the need for reheat. However, the reheat process is extremely important in dehumidification applications. The cold, 100% RH air leaving the air-handling units (AHUs) needs to be warmed up to eliminate the potential for surface condensation to occur in the space, and to eliminate condensation in the space, which is critical to the control of mold and biological growth.

The High Efficiency Dehumidification System (HEDS) is a patent-protected, proprietary energy recovery method designed to save more than 50% of the dehumidification-related cooling and heating plant energy in RH controlled environments while also eliminating the health, wellness, product, and productivity loss risks caused by poor RH control. HEDS is designed to be simple and easily maintainable, and to require knowledge of only basic Heating, Ventilating, and Air-Conditioning (HVAC) system operations. HEDS is designed to be scalable, from the smallest room level equipment to the largest central system equipment.

OBJECTIVE OF THE DEMONSTRATION

The objective of this project is to validate the performance of a new HVAC dehumidification technology designed to significantly reduce energy use associated with dehumidification, while improving indoor air quality and reducing potential for mold growth. Performance claims, installation costs, and maintenance impacts were investigated through the installation of two test units at Tinker Air Force Base (AFB), OK and Fort Bragg, NC. The primary objective of this part of the project was to evaluate the cost and performance of the HEDS technology, specifically by investigating performance claims, installation costs, and maintenance impacts through the installation of two test units at Tinker AFB, OK and Fort Bragg, NC.

TECHNOLOGY DESCRIPTION

The HEDS technology is very simple. It is comprised of a standard AHU built with a pair of deep, low face velocity heat transfer coils: a cooling coil and a cooling recovery coil. The first coil does the cooling and dehumidifying, the second coil uses the warm water leaving the cooling coil and does the reheating for RH control and cuts the loads on the chiller and boiler plants by using the low-quality recovered cooling energy to meet reheat loads. The result is a dehumidification system that is energy efficient, maintainable, and resilient.

DEMONSTRATION RESULTS

Two test units were installed, a Variable Air Volume (VAV) system at Tinker Air Force Base (AFB), OK and a constant air volume (CAV) system at Fort Bragg, NC. This report summarizes the observed field performance results from more than 6 months of real world testing for both sites. Performance tests were conducted across a range of supply air dew point temperatures to emulate the needs of various building types in the U.S. Department of Defense (DoD), General Services Administration (GSA), VA, and Federal building portfolios.

For the constant volume system at Fort Bragg, the peak day cooling load savings was 18%, while the average cooling load reduction was 25%. For the VAV system at Tinker AFB, the peak day cooling load savings was 29%, while the average cooling load reduction was 28%. The peak load reductions effectively expand the capacity of the existing chilled water systems, enabling the chiller plants to serve more cooling loads with the installed capacity, or to be downsized in the future or for new construction projects. Both of these benefits can help to reduce capital costs.

Based on the results from the Fort Bragg, NC and Tinker AFB, OK HEDS Environmental Security Technology Certification Program (ESTCP) tests, the energy reclamation function of HEDS is able to significantly reduce the cooling load associated with dehumidification while completely eliminating the need for additional reheat energy to provide RH control in a variety of facility types. Cooling load savings range from 20 to 37% depending on the application, and the dehumidification-related heating energy savings associated with the reheat function at the AHU is 100% in all cases.

Note that the actual cooling energy percentage savings that will show up at the utility meter can be a much greater figure than the cooling load savings percentage. This is due to the non-linear relationship between energy use and load on modern variable speed equipment such as pumps, fans and chillers. For example, reducing the cooling load on chilled water pumps with variable speed drives by 20% typically results in electricity savings of around 40%.

The results from the two ESTCP test sites indicate that HEDS exceeded the energy savings targets by a significant amount. Chiller plant energy savings related to the dehumidification process varied between 32% for hospital-type applications with 24/7 cooling loads, to 64% for administrative type VAV cooling loads that only need conditioning 12/5, but that are typically run 24/7 during the dehumidification season in humid climates. Reheat energy savings related to the dehumidification process was 100% for the test sites.

IMPLEMENTATION ISSUES

A major barrier to acceptance of the HEDS is market skepticism with new technologies that claim high savings levels. More technology demonstration projects in different applications and third-party validations is needed to substantiate the savings shown in this demonstration. The simplicity of the HEDS design and operating strategy should help to overcome any reluctance to embrace this new technology. Note that the latest version of American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 90.1 prescriptive energy codes explicitly disallows any form of simultaneous cooling and heating or reheating of air for RH control if the heat or reheat is not from a reclaimed or solar-thermal source. Since HEDS uses reclaimed energy for the reheat energy source, it will be a cost-effective solution to provide ASHRAE 90.1 compliance across a wide range of HVAC system sizes and types.

HEDS units are currently only available under license with one manufacturer, which can limit procurement options. Given that AHUs are mostly built to order using licensed technology or components, HEDS units will need to use the same market channels of mechanical product vendors, installers, and AHU manufacturers to achieve market scale. This will require further engineering support from the vendor networks, which requires training, education, and experience with HEDS systems.

Both demonstration sites had issues with failing chillers that led to high chilled water supply temperatures from the chiller plants. Even as chilled water supply temperatures rose as high as 60 °Fahrenheit (°F), both HEDS units were able to continue to provide dehumidification while reducing cooling loads by 16 to 30%. The cooling load saved by the HEDS unit was used by the other AHUs on the chilled water system, which provided added cooling to those spaces and led to improved comfort, productivity, health, and wellness, even when the chiller performance was sub-optimal. A HEDS installation can improve resiliency by doing more with less.

Throughout the demonstration, HEDS was shown to have the same, or slightly lower, maintenance needs than a normal AHU; thus, the needs are significantly lower than other commercial dehumidification technologies. Technology transition is occurring through ongoing presentations, white papers, and direct project analysis with Federal energy managers and vendors, showing performance results and discussing implementation strategies for HEDS.

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1.0 INTRODUCTION

1.1 BACKGROUND

Proper relative humidity (RH) control is critical to maintaining healthy and productive indoor environments in buildings. It is estimated that U.S. companies waste as much as \$48 billion annually covering medical costs and \$160 billion annually in lost productivity as a result of sick-building syndrome. (Mumma, 2006) Mold remediation costs associated with poor RH control have been observed to top \$1 million annually on military bases. Proper RH control minimizes the potential for indoor air quality problems and related sick-building illnesses while improving thermal comfort and productivity.

The current “industry standard” method to control RH and biological growth involves sub-cooling air to condense moisture out of the air, then reheating the same air that was just subcooled to reduce the relative humidity of the air before it enters the space. This method has been around and used for over 100 years and is known to be very energy intensive due to the need for reheat. However, the reheat process is extremely important in dehumidification applications. The cold, wet air leaving the Air-Handling Units (AHUs) needs to be warmed up to eliminate the potential for surface condensation to occur in the space, and condensation already present in the space, which is critical to the control of mold and biological growth.

Unfortunately, the Heating, Ventilating, and Air-Conditioning (HVAC) systems at many Federal facilities are not even equipped with the required reheat function. Many more facilities do not use the installed reheat function, as the energy expense is very high, and “common sense” tells people that you should not be running boilers to produce 180 °Fahrenheit (°F) hot water in the middle of the summer in humid environments, even though it is needed to perform the required reheat function. As a result, many Federal facilities have the compounded problems of excessive energy use, excessive biological growth, and HVAC system design or operation that actually promotes mold growth.

To resolve those problems, the U.S. Army Corps of Engineers (USACE) approached Retrofit Originality Inc. in 2006 to develop a cost effective, energy efficient, maintainable, and scalable dehumidification and RH control solution that would work in retrofit applications as well as new construction. Substantial research, development and computer modeling resulted in the High Efficiency Dehumidification System (HEDS). HEDS is a patent-protected, proprietary energy recovery method designed to save more than 35% of the cooling and heating energy in RH controlled environments while also eliminating the health, wellness, product and productivity loss risks caused by poor RH control.

1.2 OBJECTIVE OF THE DEMONSTRATION

The main technical objective of this project was to evaluate the HEDS unit design in two real world buildings to determine if there are technical issues that must be addressed before full scale commercialization. Additional objectives were to quantify the extent to which systems can be downsized, to assess the level of improved efficiency of the systems, and to determine the extent to which upgrade costs are able to be reduced.

1.3 REGULATORY DRIVERS

A number of regulatory drivers support the application of HEDS technology, most of which were associated with goals to reduce the annual energy use intensity (EUI) of Federal buildings. This is dictated primarily by the Energy Policy Act of 2005. This project directly supports attainment of these goals in a cost-effective manner by reducing the amount of energy used in the HVAC system for dehumidification, reheat and cooling energy. In a typical U.S. Department of Defense (DoD) building, the HVAC energy is about 30 to 40% of total energy. The energy for cooling, dehumidification and reheat for RH control is up to 40% of the total energy in humid climates (much higher in very humid climates). Proper applications of this technology should reduce that amount by an average in the range of 30 to 40%, thereby reducing the energy total by about 5% for the total building energy use.

The application of this one technology breakthrough can help the DoD meet almost 2 years' worth of energy intensity reduction goals for a 3% energy intensity annual reduction. This technology may also result in potential water savings for systems that use open cooling towers for heat rejection, but this will not be validated as part of this project.

Key regulatory drivers include:

- Executive Orders: Executive Order (EO) 13423, EO 13514, EO 13693
 - <http://www.whitehouse.gov/administration/eop/ceq/sustainability>
 - <https://www.federalregister.gov/articles/2015/03/25/2015-07016/planning-for-federal-sustainability-in-the-next-decade>
- Legislative Mandates: Energy Policy Act of 2005, Energy Independence and Security Act of 2007, National Defense Authorization Act (NDAA) for Fiscal Year 2015 <http://www.armed-services.senate.gov/press-releases/senate-committee-on-armed-services-reach-agreement-with-house-counterparts-regarding-the-national-defense-authorization-act-for-fiscal-year-2015>
- Federal Policy: Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding (MOU) 2006
- DoD Policy: Strategic Sustainability Performance Plan, Energy Security MOU with U.S. Department of Energy (DOE)
- Service Policy: Army Sustainable Design and Development Policy Update, December 16, 2013 http://www.usace.army.mil/Portals/2/docs/Sustainability/Hydrology_LID/ASAIEE_SDD_Policy_Update_2013-12-16.pdf, Secretary of the Navy Energy Goals http://www.navy.mil/features/Navy_EnergySecurity.pdf, Air Force Sustainable Design and Development Implementing Guidance
 - http://www.wbdg.org/ccb/AF/POLICY/af_sdd_impl_guidance.pdf
 - <http://www.safie.hq.af.mil/shared/media/document/AFD-091208-027.pdf>

- Guides: Whole Building Design Guide (<http://www.wbdg.org/>). See specifically:
 - http://www.wbdg.org/pdfs/usace_dg_epact2005.pdf
 - http://www.wbdg.org/references/mou_ee.php
- Specifications: American Society of Heating, Refrigerator, and Air-Conditioning Engineers (ASHRAE) Standards 62.1 and 90.1, Leadership in Energy and Environmental Design [LEED], Institute of Electrical and Electronics Engineers [IEEE], International Code Council (ICC) Codes (International Mechanical Code [IMC], International Plumbing Code [IPC], International Energy Conservation Code [IECC,] etc.).

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

HEDS reclaims some of the very low-quality heat generated during the cooling and dehumidification process in the chilled water stream and uses it to provide the reheat energy used to lower the RH of the air supplied to buildings, reducing the potential for condensation to occur and reducing reheat requirements to ensure that spaces are not overcooled due to dehumidification processes. The energy reclaimed for reheat has a compounding benefit: every British Thermal Unit (BTU) of energy used for re-heat also reduces the cooling load on the chiller plant by the exact same amount.

2.2 SYSTEM DESCRIPTION

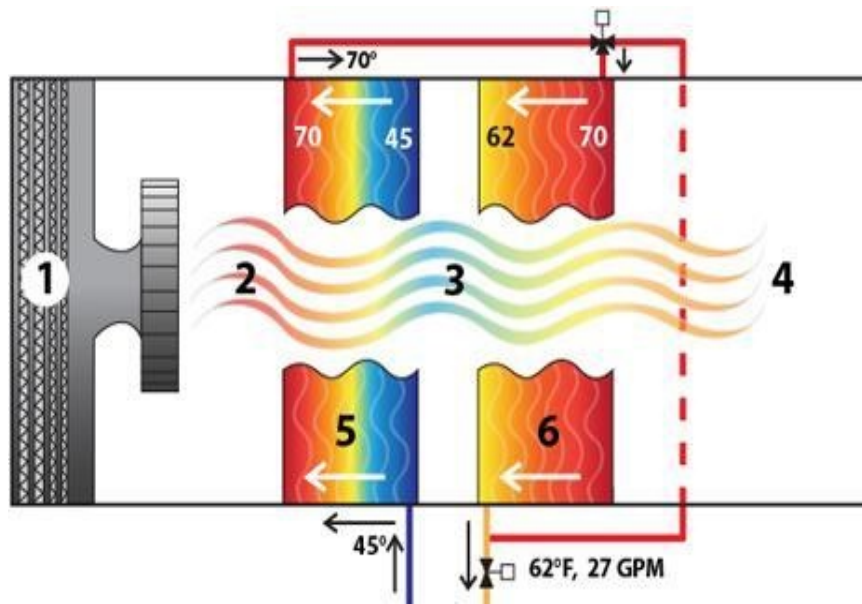


Figure 1. High Efficiency Dehumidification System.

As shown in Figure 1, the HEDS units use very large, low air face velocity cooling and cooling recovery coils, low chilled water (CHW) flow rates, high CHW temperature differential and low air-handling unit (AHU) air pressure drops. In the HEDS unit, 45 °F CHW enters the cooling coil (5) at 27 gallons per minute (GPM) and leaves the cooling coil at 70 °F. This 70 °F water then enters the cooling recovery coil (CRC) (6) at 27 GPM and leaves the CRC at 62 °F while heating the air from 55 °F up to 65 °F. (**Data Points 1 thru 4:** [1] 10,000 cubic feet per minute (CFM) airflow [2] 78 °F dry bulb temp, 65 °F wet bulb temp [3] 55 °F dry bulb, 55 °F dewpoint, essentially 100% relative humidity [4] 65.3 °F dry bulb, 55 °F dewpoint, 55% RH.) The HEDS unit requires **226,187 BTU/hr** to cool, dehumidify and reheat 10,000 CFM of air, a total British Thermal Unit per Hour (BTUH) savings of 53% and a CHW flow reduction of 62% in this example compared to a similar subcool reheat AHU.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

HEDS AHUs have many advantages over existing dehumidification systems solutions. Some of the most common other dehumidification designs applicable to CHW systems are: Chilled Water/Direct Expansion Coils with Gas or Electric Reheat, Run-Around Coils, Heat Pipe Coils, Rotary Wheel Heat Exchangers, Air to Air Heat Exchangers, and Desiccant Dehumidification Wheels.

These technologies have significant limitations when compared with HEDS, including:

- Increased maintenance costs due to complexity of additional fluid stream, pumps, heat recovery wheels, heat exchangers, motors, belts, and other components,
- Potentially decreased CHW system temperature differential due to smaller coils and reduced inlet air temperatures to the cooling coil, leading to the “Low Delta T Syndrome,” which can increase central plant energy use and reduce cooling system usable capacity,
- Poor temperature control due to uncontrolled inlet temperatures from heat recovery coils,
- Added regeneration heat energy and post-wheel cooling with some desiccant designs,
- Much longer, taller, or heavier AHUs,
- Higher air pressure drop and fan energy due to additional upstream and downstream coils and wheels that require more fan energy,
- Condensate re-evaporation when water is blown off the cooling coil, into the fan or ductwork, and
- Designs not scalable to room/fan coil unit (FCU) sizes, where many of the problems are found.

2.3.1 Performance Advantages of the HEDS Technology

The HEDS unit uses the very low-quality heat that is generated during the cooling and dehumidification process to provide the necessary reheat energy to lower the RH of the supply air. This in turn reduces the potential for moisture condensation in AHU’s ducts and occupied spaces, and reduces the cooling load on the chiller plant. This cooling load reduction in BTUs is equal to the amount of recovered energy that is used to provide reheat. For RH control processes, this eliminates the need for a supplemental reheat source in many climates, thereby substantially reducing both chiller plant and heating plant energy consumption. Many bases are equipped with “two-pipe” water distribution systems that eliminate the possibility for the reheat portion of the cooling/dehumidification/reheat cycle, making RH control impossible. With a two-pipe system, the pipes are filled with cold water in the summer, and the AHU heat transfer coils act as cooling coils, while in the winter, the pipes are filled with hot water, and the AHU heat transfer coils act as heating coils.

Heating and cooling cannot occur at the same time. Since there is no ability to provide heating for reheat during the dehumidification (cooling) season, RH control is not possible. HEDS can work with two-pipe water distribution systems where other systems may not work because the reheat energy source for HEDS units is the warmed up, but low-quality heat transferred from the cooling load of the mixed air and AHU fan and motor heat into the CHW return line.

The large face area coil design reduces the air velocity thru the AHU, which provides a >50% reduction in air filter and coil air pressure drop, and the lower required cooling water flow rate results in >70% pumping energy reduction for the loads served by HEDS units. The combined air pressure drop of the Cooling Coil (CC) and CRC is approximately 50% lower than a typical cooling coil and reheat coil combination due to the very large face area of the HEDS coils and the associated very low air velocities thru the coils.

2.3.2 Cost Advantages of the HEDS Technology

A benefit of HEDS is that the CHW flow rate required to meet peak day cooling/dehumidification needs will be reduced by approximately 50 to 60% compared to typically installed AHU systems. On sites that may be at the capacity limits of their piping infrastructure, the ability to meet the same cooling loads with a 50 to 60% reduction in the CHW flow rate can mean that the avoided costs from not having to replace or augment the piping infrastructure can cover most or all of the costs of HEDS retrofit projects.

For many installations, if HEDS is not used, in order to provide code mandated RH control to facilities equipped with two-pipe water distribution systems, reheat energy for RH control needs to be provided by electric strip heaters, which will not comply with new energy codes. The electrical infrastructure of most facilities is inadequate to provide this added power requirement to the buildings and down to the AHU level, so the facilities that need RH control typically go without RH control. This has led to the current situation with widespread biological growth and high biological remediation costs.

Since the HEDS unit is a normal AHU built with very large cooling and CRCs, it is no more complex or costly to operate and maintain than a conventional AHU. A basis of its design is that it is intended to be maintained by HVAC mechanics with a basic level of maintenance training to reduce the lifecycle cost on the unit. This contrasts with other systems, such as desiccant driven or direct expansion (DX) type dehumidifiers, which require specialized maintenance and operations knowledge and added energy use to perform RH and temperature control in comparison to the HEDS unit.

To put the terms “very large coils” and “large face area coil design” into better perspective, Table 1 lists data that may be used to compare three different size units that would work for the cooling/dehumidification/reheat process.

Table 1. AHU Sizes Suitable for Cooling/Dehumidification/Reheat Process.

CFM/AHU Design	Approximate AHU Width	Approximate AHU Height	Approximate W x H Change to Implement HEDS Units
5,000/Non-HEDS (inadequate coil sizing)	58 in.	58 in.	(base case does not work properly)
5,000/HEDS	72 in.	72 in.	14 x 14-in. larger
5,000/Non-HEDS (adequate coil sizing)	65 in.	65 in.	
5,000/HEDS	72 in.	72 in.	7 x 7-in. larger
10,000/Non-HEDS (inadequate coil sizing)	75 in.	75 in.	(base case does not work properly)
10,000/HEDS	94 in.	94 in.	19 x 19-in. larger
10,000/Non-HEDS (adequate coil sizing)	85 in.	85 in.	
10,000/HEDS	94 in.	94 in.	9 x 9-in. larger
25,000/Non-HEDS (inadequate coil sizing)	107 in.	107 in.	(base case does not work properly)
25,000/HEDS	138 in.	138 in.	31 x 31-in. larger
25,000/Non-HEDS (adequate coil sizing)	122 in.	122 in.	
25,000/HEDS	138 in.	138 in.	16 x 16-in. larger

Field audits have shown that there are a multitude of undersized cooling coils installed at a multitude of different bases. These coils are undersized to the point that they cannot perform adequate cooling and dehumidification duties. Table 1 lists data that describe two different performance levels for equipment at three different size ranges. The first is the typically undersized cooling coil selection, and the second is a coil selection that will actually meet dehumidification needs. Typically, undersized dehumidification coils use four to eight rows at an approximate 550 feet (ft)/minute face velocity. Adequately sized dehumidification cooling coils require eight rows of coils, at an approximate 350 ft/minute face velocity. HEDS units typically use eight- to 10-row cooling coils at a 200 to 300 ft/minute face velocity. A 10-row coil is 3 in. deeper than an eight-row coil.

The overall length change is approximately the same for all sizes, as coil depth is the main contributor to changes in length. The HEDS units will typically be 14 to 18 in. longer than the non-HEDS units.

As can be seen, the overall dimensional changes are not that significant, especially when the comparison is made to units that have coils adequately sized to meet the required dehumidification loads. The HEDS units will be significantly smaller than other energy recovery designs. Many of the other dehumidification-related energy recovery designs or RH control designs, such as desiccant wheels, sensible and total enthalpy wheels, and run-around coils will not fit into existing mechanical spaces and may be too heavy to be roof-mounted on existing support structures.

In a recent field study to determine the potential for HEDS implementations for five different ship classes for the Navy, it was found that there was adequate room to install full size HEDS units in approximately 90% of the mechanical spaces, with the remaining 10% of the units being near full size (>80% capabilities). We do not believe that there are any other technologies that offer the same benefits and performance that would fit those spaces.

2.3.3 Performance Limitations of the HEDS Technology

Adequate physical space will need to be allocated for the HEDS units. In very tight mechanical spaces, the HEDS unit may not fit, as HEDS units are typically physically larger than a typical non-HEDS design sub-cool–reheat AHU. For built-up AHUs, there may be adequate space within the existing AHU frame to fit the HEDS technology. Where there is a lack of space in a very tight mechanical room, it may be possible to locate the HEDS unit next to the loads and cut it into the required point of connection. Note, however, that HEDS units will typically be smaller than a desiccant wheel-based system that delivers the same air conditions. Energy consumption and reliability/maintainability are also enhanced in comparison to the other technologies typically used for RH control.

The lowest reasonable dewpoint temperature that a HEDS unit can provide without requiring defrost cycles is approximately 35 °F, so many industrial processes can use HEDS. For process loads that need to be provided with ultra-low dewpoint air, some form of a desiccant-based system will most likely be the most effective option, as long as there are adequately trained mechanics and an appropriate maintenance budget allocated for this system.

As a major intent of the HEDS technology is to cool and dehumidify conditioned air in a more efficient and lifecycle cost effective way, the HEDS units will work best at geographic locations that have a hot and humid climate for at least 4 months of the year, or that are in milder climates, but that need to provide 48 to 50 °F dewpoint air to their cooling loads, such as hospitals and clean room environments located in the Southwest or precision semiconductor and pharmaceutical manufacturing facilities across much of the United States.

2.3.4 Cost Limitations of the HEDS Technology

The cost effectiveness of the HEDS units may be very site specific. On standalone implementations of an HVAC unit that is not currently equipped to provide the “reheat” part of the dehumidification-reheat process, the HEDS unit may be less costly than trying to create and implement a new reheat energy source, or to convert the unit to one of the other dehumidification/reheat strategies, especially if the installation must be compliant with an energy code that forbids simultaneous heating and cooling for RH control.

Conversely, if a facility has a four-pipe water distribution system and runs the boilers all summer long in addition to running the chillers, and the AHUs are already equipped with reheat coils (not just preheat coils), the HEDS unit may have a higher first cost. However, the lower operating expenses or other cost offsets, such as reduced capital expenditures for chillers, pipes, pumps, cooling towers, and chiller plant physical room expansions may make it cost effective.

For facilities operating under a mandate to reduce energy and water consumption, the efficiency benefits of the HEDS unit may make it a lifecycle cost effective solution, even if it has a higher first cost.

Non-energy benefits such as improved health and wellness, energy resiliency, improved use of renewable energy, and the fact that lives may be saved through the reduction of Healthcare Acquired Infections (HAIs) are non-trivial and may be the driving forces behind HEDS implementations. In other words, although energy benefits are important, they may not be the main reason for the implementations.

3.0 PERFORMANCE OBJECTIVES

Table 2 and 3 summarize the performance objectives and results for each test site. All success criteria were met, and often substantially exceeded, across all objectives at both test sites.

Table 2. Quantitative Performance Objectives Results Summary for the Fort Bragg Test Site.

Performance Objective	Metric	Data Requirements	Success Criteria	Results (†CHWST <46 °F)
1. Peak Cooling Load Reduction %	Thermal Energy (Tons Refrigeration, kilowatt (kW), million BTU (MMBtu))	Refrigeration tonnage, CC load, CRC load, supply and return water temperatures, CHW flow rate through CC and CRC	Reduce 15-minute peak cooling load by 15% on a peak cooling load day during the demonstration period	18.3%
2. Greatest Cooling Load Reduction %	Thermal Energy (Tons Refrigeration, kW, MMBtu)	Refrigeration tonnage, CC load, CRC load, supply and return water temperatures, CHW flow rate through CC and CRC	Highest cooling load % reduction exceeds 20% during the demonstration period	37.4%
3. Dehumidification /Reheat Coil Energy Reduction	Thermal Energy (Tons Refrigeration, kW, MMBtu)	CC load, CRC load, CHW supply and return temperatures, CHW flow rate through CC and CRC, reheat coil (RHC) load, hot water supply and return temperatures, RHC flow	CRC coil eliminates the need for at least 90% of the RH-control-related reheat energy required from the reheat coil when the system is in dehumidification-reheat mode during the demonstration period	100.0%
4. Enhance Space Comfort Conditions	Space and return air conditions compared to Unified Facilities Criteria (UFC) comfort zone for summer	Space drybulb and dewpoint temperatures, space RH%, return air drybulb and dewpoint temperatures, return air RH%	Space conditions fall within UFC comfort guidelines more than 90% of the time during occupied hours	96.0%
5. Reduce Cooling Ton-Hours Consumption	Thermal Energy (Tons Refrigeration, kW, MMBtu)	CC load, CRC load, supply and return water temperatures, CHW flow rate through CC and CRC	Cooling ton-hours associated with the HEDS unit are reduced by the cooling recovery coil by 7.5% compared to the ton-hours consumed by the cooling coil during the time that the HEDS is in dehumidification-reheat mode during the demonstration period	24.7%
6. Improve “Low Delta T” Syndrome	Temperature and flow measurements and/or calculations	HEDS CC CHW Temperature Drop (TD) and flow, HEDS CRC CHW TD and flow, HEDS unit CHW TD and flow	HEDS average CHW system TD exceeds 14 °F during the time that the HEDS is in the cooling or dehumidification-reheat modes during the demonstration period	17.1 °F

Table 2. Quantitative Performance Objectives Results Summary for the Fort Bragg Test Site. (Continued)

Performance Objective	Metric	Data Requirements	Success Criteria	Results (†CHWST <46 °F)
7. Reduce Greenhouse Gas (GHG) Emissions	Fossil fuel GHG emissions (metric tons)	Information in #8 and estimated source energy GHG production for cooling and reheat energy sources	GHG emission reductions exceed 3% (annual comparison)	45-79%*
8. Reduce Energy cost of Dehumidification/Reheat process	%, \$	HEDS estimated kWh/ton-hour for chiller plant, HEDS cooling ton-hours for dehumidification, HEDS CRC tons/MMBTU, calculated RHC energy use, estimated chiller and boiler plant system efficiency, kWh and therms Average cost/kWh and cost/therm for Natural Gas (NG)	Cost of Dehumidification and reheat with HEDS vs. Control Valve (CV) subcool/terminal reheat is reduced by 10% during dehumidification-reheat modes of operation	41-51%+**
9. System Economics Reduce Lifecycle cost of Dehumidification/Reheat process	%, \$, years	Estimated and calculated dollar costs and savings, discount rate, usable life	5% reduction in lifecycle costs	Retrofit: 26-29%+** New construction/end of useful life (EUL): 38-44%+**

* Savings vary based on central plant chiller and heating system efficiencies; uses eGrid national average electricity emissions factors.

** Savings vary based on central plant chiller and heating system efficiencies, as well as electricity and gas commodity rates. Average potential savings over a range of potential cost, efficiency, and reheat source scenarios is shown.

† Chilled Water Supply Temperature

Table 3. Quantitative Performance Objectives Results Summary for the Tinker Air Force Base (AFB) Test Site.

Performance Objective	Metric	Data Requirements	Success Criteria	Results (CHWST <46 °F)
1. Peak Cooling Load Reduction %	Thermal Energy (Tons Refrigeration, kW, MMBtu)	Refrigeration tonnage, CC load, CRC load, supply and return water temperatures, CHW flow rate through CC and CRC	Reduce 15-minute peak cooling load by 15% on a peak cooling load day during the demonstration period	28.9%
2. Greatest Cooling Load Reduction %	Thermal Energy (Tons Refrigeration, kW, MMBtu)	Refrigeration tonnage, CC load, CRC load, supply and return water temperatures, CHW flow rate through CC and CRC	Highest cooling load % reduction exceeds 20% during the demonstration period	28.7%
3. Dehumidification /RHC Energy Reduction	Thermal Energy (Tons Refrigeration, kW, MMBtu)	CC load, CRC load, CHW supply and return temperatures, CHW flow rate through CC and CRC, RHC load, hot water supply and return temperatures, RHC flow	CRC coil eliminates the need for at least 90% of the RH-control-related reheat energy required from the reheat coil when the system is in dehumidification-reheat mode during the demonstration period	100.0%
4. Enhance Space Comfort Conditions	Space and return air conditions compared to UFC comfort zone for summer	Space drybulb and dewpoint temperatures, space RH%, return air drybulb and dewpoint temperatures, return air RH%	Space conditions fall within UFC comfort guidelines more than 90% of the time during occupied hours	98.0%
5. Reduce Cooling Ton-Hours Consumption	Thermal Energy (Tons Refrigeration, kW, MMBtu)	CC load, CRC load, supply and return water temperatures, CHW flow rate through CC and CRC	Cooling ton-hours associated with the HEDS unit are reduced by the cooling recovery coil by 7.5% compared to the ton-hours consumed by the cooling coil during the time that the HEDS is in dehumidification-reheat mode during the demonstration period	27.6%
6. Improve “Low Delta T” Syndrome	Temperature and flow measurements and/or calculations	HEDS CC CHW TD and flow, HEDS CRC CHW TD and flow, HEDS unit CHW TD and flow	HEDS average CHW system TD exceeds 14 °F during the time that the HEDS is in the cooling or dehumidification-reheat modes during the demonstration period	24 °F
7. Reduce GHG Emissions	Fossil fuel GHG emissions (metric tons)	Information in #8 and estimated source energy GHG production for cooling and reheat energy sources	GHG emission reductions exceed 3% (annual comparison)	70-86%*

Table 3. Quantitative Performance Objectives Results Summary for the Tinker Air Force Base (AFB) Test Site. (Continued)

Performance Objective	Metric	Data Requirements	Success Criteria	Results (CHWST <46 °F)
8. Reduce Energy cost of Dehumidification/ Reheat process	%, \$	HEDS estimated kWh/ton-hour for chiller plant, HEDS cooling ton-hours for dehumidification, HEDS CRC tons/MMBTU, calculated RHC energy use, estimated chiller and boiler plant system efficiency, kWh and therms Average cost/kWh and cost/therm for NG	Cost of Dehumidification and reheat with HEDS vs. CV subcool/ terminal reheat is reduced by 10% during dehumidification-reheat modes of operation	68-75%+**
9. System Economics Reduce Lifecycle cost of Dehumidification/ Reheat process	%, \$, years	Estimated and calculated dollar costs and savings, discount rate, usable life	5% reduction in lifecycle costs	Retrofit: 13-41%+** New construction/ EUL: 43-61%+**

* Savings vary based on central plant chiller and heating system efficiencies; uses eGrid national average electricity emissions factors.

** Savings vary based on central plant chiller and heating system efficiencies, as well as electricity and gas commodity rates. Average potential savings over a range of potential cost, efficiency, and reheat source scenarios is shown.

4.0 SITE DESCRIPTION

4.1 FACILITY/SITE LOCATION AND OPERATIONS

Two locations were selected for the pilot demonstration. The first is at Tinker Air Force Base (AFB), OK in Bldg. 3, an administrative building, and the second is at Fort Bragg, NC in Bldg. A-3556, a Dining Facility (DFAC). Both Fort Bragg and Tinker AFB are in Department of Energy Climate Zone 3A, which is defined as “Warm – Humid.”

The selected installations are representative of those located in climates that have at least 4 months each year of dehumidification. This represents a large percentage of military installations worldwide. The two types of buildings chosen were an administrative building and a DFAC, which represent a large portion of building stock across the DoD and General Services Administration (GSA). The administrative/office facility is supposed to operate with a 5 days/week, 12 hr/day HVAC schedule, and is representative of office types of facilities. The DFAC has variable occupancy and relatively long operating hours, and is representative of many other DoD facilities, even barracks to some extent. Both sites have ongoing problems with biological growth, odors, and a “musty feel” associated with high internal RH and biological growth. Figure 2 shows the respective new HEDS units.

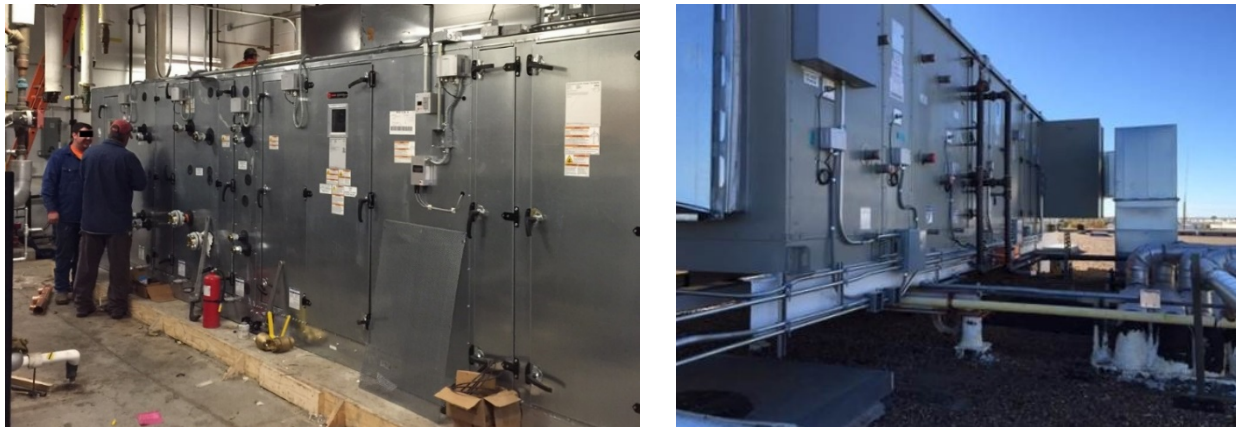


Figure 2. New HEDS AHU on Bldg. A-3556 at Fort Bragg (left) and Bldg. 3 at Tinker AFB (right).

4.2 FACILITY/SITE CONDITIONS

At Fort Bragg, there are a total of four AHUs serving the facility, three existing AHUs in addition to the new HEDS AHU that replaced the original constant air volume (CAV) AHU serving the kitchen. All are fed from the same CHW plant. The existing AHUs serving the facility are currently undersized, requiring that they be run 24x7 in an attempt to maintain comfortable and dehumidified operations for the kitchen, serving area, and the two dining halls. Additionally, throughout the monitoring period, the chiller experienced significant capacity constraints due to failed sensors that limited the compressor staging, effectively limiting the chiller output to roughly 50% of rated capacity. As a result of this decreased capacity, CHW supply temperatures from the plant were routinely above the design range of 42 to 46 °F. In fact, the CHW supply temperature was below 46 °F, or “in control,” less than 50% of the monitoring period.

Due to the issues observed in the CHW systems at both locations, the performance data had to be “binned” into CHW supply temperature ranges to explore the impact of HEDS across a range of CHW supply conditions, from “in control” design conditions (CHWS temperature less than 46 °F) to out of control failing systems with CHW supply temperatures above 62 °F. Increased CHW supply temperatures from the plant lead to decreased cooling and dehumidification capacities in the AHUs, as well as reduced potential energy for the HEDS unit to use for RH control.

5.0 TEST DESIGN

This section describes the system design and testing conducted during the demonstration.

5.1 CONCEPTUAL TEST DESIGN

Hypothesis: The HEDS system will reduce the energy consumed by an HVAC system while simultaneously providing RH and space dewpoint control without the use of additional equipment or energy sources.

Test Design: The test design is to serve the cooling/dehumidification loads of a facility with the HEDS unit and compare the HEDS unit energy consumption and performance to a hypothetical “normal” AHU that performs cooling, dehumidification, and reheat duties, serving the identical loads.

Since “the load is the load,” the number of BTUs required to cool the air down and the amount of BTUs required to reheat the air back up to meet comfort conditions and control space RH will be measured. From this data, the avoided BTUs of reheat energy that the CRC airside temperature increase provides will be measured, equating to the decreased cooling load that has to be served by the chiller plant. The cooling load on the chiller plant is reduced due to the reduced CHW return temperature associated with the cold supply air coming off the CC and entering the CRC. The cold air coming off of the CC being blown thru the CRC cools the CHW return going back to the chiller plant, removing the same amount of load from the chiller plant that was added to the supply air in the reheat process by the CRC. By measuring only the chilled water flow rate, entering CHW temp to the cooling coil, leaving CHW temp from the cooling coil, and leaving CHW temp from the HEDS unit, the baseline case cooling load and reheat loads can be calculated.

In this manner, the HEDS unit serves as both the baseline and the test case. Since the cooling load is known (and not impacted by the installation of the HEDS unit), and the reheat loads needed to meet comfort and RH control conditions in the space are known, a separate AHU is not needed for baseline comparison.

Test Phases: HEDS Unit commissioning and startup, initial data collection and evaluation, HEDS unit operation and ongoing data collection and evaluation, and required report development.

5.2 BASELINE CHARACTERIZATION

The baseline energy use will be measured continually as a part of the test. The baseline consists of the cooling energy in ton-hours that is consumed in the cooling and dehumidification process, and the reheat energy that is used to reheat the supply air to reduce the RH of the air and the spaces being conditioned. These cooling and reheat loads are the same as for the HEDS case.

Existing Baseline Data: The loads that are being served on a continuous basis are the baseline data, as well as the HEDS data. As noted elsewhere, the main difference will be the calculations for the reheat energy source, be they CRC-sourced or new energy sourced (such as from a gas boiler).

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

System Design:

- The HEDS units replaced the existing under-performing AHUs. Everything between the supply and return ductwork points of connections was replaced. At Tinker AFB, the downstream ductwork-mounted RHC was left in place.
- The HEDS units are connected into the existing ductwork and piping systems in close proximity to the current piping and ductwork points of contact (POC). The piping and ductwork sizes were not changed past the POCs, and there were no changes to any interior ductwork.
- For the Fort Bragg DFAC unit, the motor horsepower (HP) was upgraded from 10 HP to a 15 HP system, and now include a variable frequency drive (VFD) instead of using a two-speed motor for volume control when the exhaust fan 39 is on or off. This was done because the Fort Bragg HVAC system had been described as problematic in terms of total air flow capacity; areas of the kitchen were perceived as uncomfortable, no air movement could be felt, and the spaces were described as “stale” or “stagnant.” To ensure that the kitchen spaces received a sufficient volume of conditioned air so that air movement could be felt, the CFM of the HEDS unit was increased in size relative to the installed equipment. This eliminated the lack of CFM as a driver underlying the success or failure of the test.
- For the Tinker AFB Roof Top Unit 4 (RTU-4) unit, the motor HP was upgraded from 7.5 HP to a 10 HP system, and now includes a VFD for static pressure control. As with the DFAC unit at Fort Bragg, the RTU-4 HVAC system was described as being problematic in terms of total capacity; a lack of CFM as a driver of the success or failure of the test was eliminated.
- The HEDS units were delivered complete with all instrumentation, valves, unit controls and trending equipment required for the test and to operate the systems. Factory testing was conducted to ensure proper operation of the components before shipment to the site.
- Each unit was equipped with a full airside economizer damper section.
- For the two test sites, the HEDS units were built with a preheat coil to match existing construction of the AHUs that were replaced as a part of this project. The preheat coils are used in cold weather climates to reduce the potential for cooling coil freeze-ups. Downstream from the preheat coil are the cooling coil and the CRC.
- The AHU replaced at Tinker AFB had a ductwork-mounted RHC located downstream from the CRC that was added to the discharge ductwork at some point in time after the initial project construction. It is not known why this RHC was installed, but it was left in place and incorporated as a part of the system. Note that this coil was never required for use during the demonstration period.
- There are no “custom” components used in the system. The HEDS unit uses standard Trane AHU construction, fans, VFDs, and coils. The instrumentation is off the shelf, but high accuracy equipment from Vaisala or Setra, and the coil control valves are the energy valve and ball valves from Belimo.

5.4 OPERATIONAL TESTING

Operational Testing of Cost and Performance:

- At Tinker AFB, several control points are hardwired between the HEDS controller and the base Building Automation System (BAS) system. These points include: HEDS start/stop, space temperature drybulb reading, space temperature dewpoint temperature reading, fan speed command, unit discharge static pressure, and unit supply air temperature.
- At Fort Bragg, at the request of the base personnel, the HEDS controller controls the unit and trends data locally.
- During the commissioning process, data were downloaded at 7- to 10-day intervals to validate the data and address any potential operational or data discrepancies before operations.
- The systems were started up and commissioned by trained Trane personnel in the field, with data validation throughout the startup and commissioning process by return on investment (ROI).

The project overall timeline is shown below for each site.

Table 4. Project Timeline for Each HEDS Installation and Data Collection Period.

Fort Bragg and Tinker AFB	2Q 2015*	3Q 2015	4Q 2015	1Q 2016	2Q 2016	3Q 2016	4Q 2016	1Q 2017
HEDS Unit Ordered from Trane		X						
HEDS Installation			X					
HEDS Startup and Cx				XXX	X			
HEDS Data Collection					XXX	XXX	X	
Data Analysis and Report Development							X	XXX

* The number of “Xs” in the column indicate the number of months in that quarter that the work was conducted

5.5 SAMPLING PROTOCOL

The data were automatically collected by the HEDS unit control system at 5-minute intervals. The HEDS unit archived the data locally and data were retrieved periodically by Trane staff for archive and analysis. Approximately 300 points were trended or calculated as described in this document for each site, and data were collected from April to November 2016. Trend data are stored locally in the HEDS unit controller and retrieved monthly via jobsite visits. The data were sent to ROI, Trane, and Construction Engineering Research Laboratory (CERL), and were archived in at least three locations for redundancy.

The data analysis results were binned into CHW supply temperature ranges to examine the HEDS performance across a range of plant operating conditions. Additionally, the results were binned into supply air temperature ranges within each CHW supply temperature bin to analyze the impact of varying levels of dehumidification as evidenced by the cooling coil supply air temperature.

5.6 SAMPLING RESULTS

5.6.1 Fort Bragg

The HEDS system demonstrated a net 21.5% cooling load reduction across all operating conditions, including times when the chiller was in a failure or capacity constraint mode of some sort. When considering only those times when the chiller plant was meeting setpoint (CHW supply temperatures were less than 46 °F), the net cooling load reduction is 24.7%.

The psychrometric analysis below highlights the impact of the CRC on the system performance. As shown, the subcooled air leaving the cooling coil at 52.5 °F is heated to 61.5 °F using recovered energy from the CHW in the CRC, completely eliminating the need for additional reheat energy.

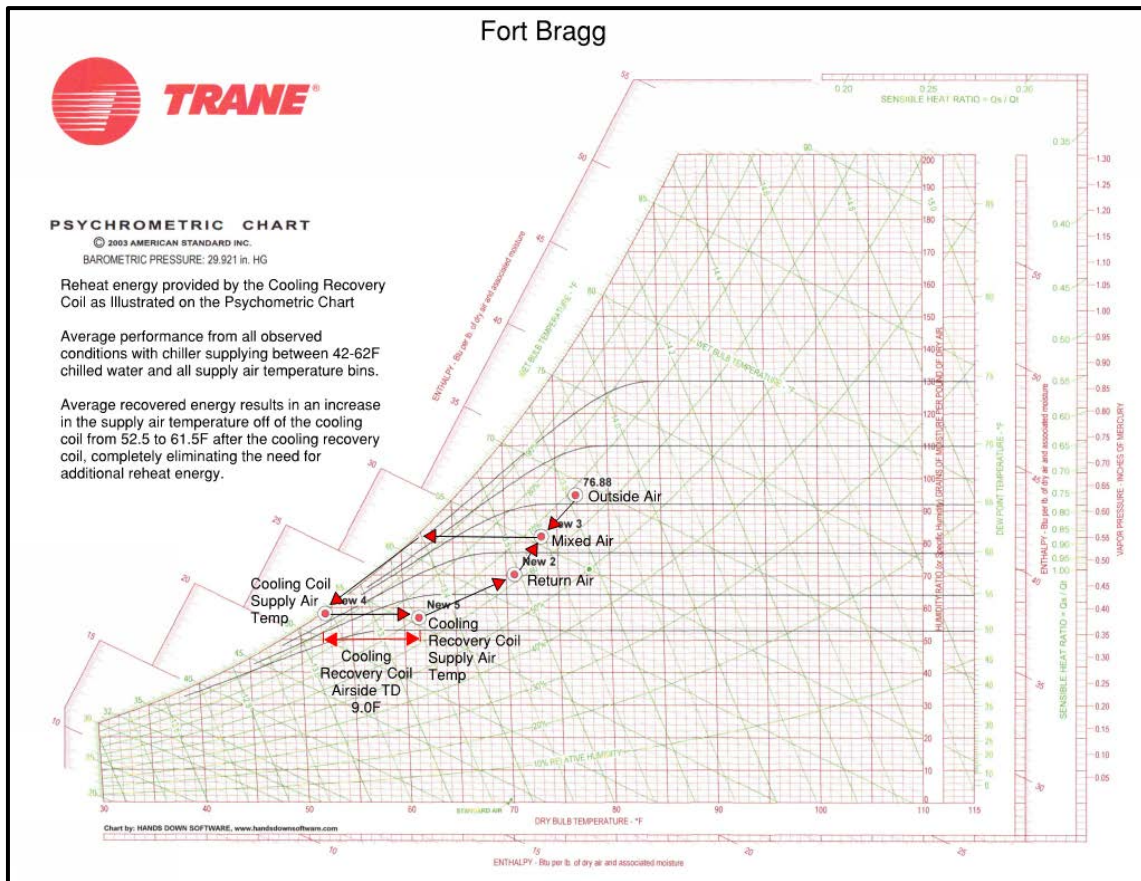


Figure 3. Psychrometric Chart Highlighting the Impact of the CRC on HEDS System Performance at Fort Bragg.

Figures 4 and 5 highlight the dynamic impact of the CRC on the net AHU cooling load for a peak cooling week and peak cooling load day in August followed by part load days in October. The impact on total load, AHU cooling coil and net differential CHW temperatures, and total energy savings percentage are shown. For the peak load week in August shown, the cooling coil supply air temperature is less than 50 °F due to the high dehumidification loads required. At this condition, the average savings from HEDS is approximately 18%. The peak cooling load day, August 5, 2016, is also shown, highlighting the savings at the time of coincident peak cooling load of 18.3%.

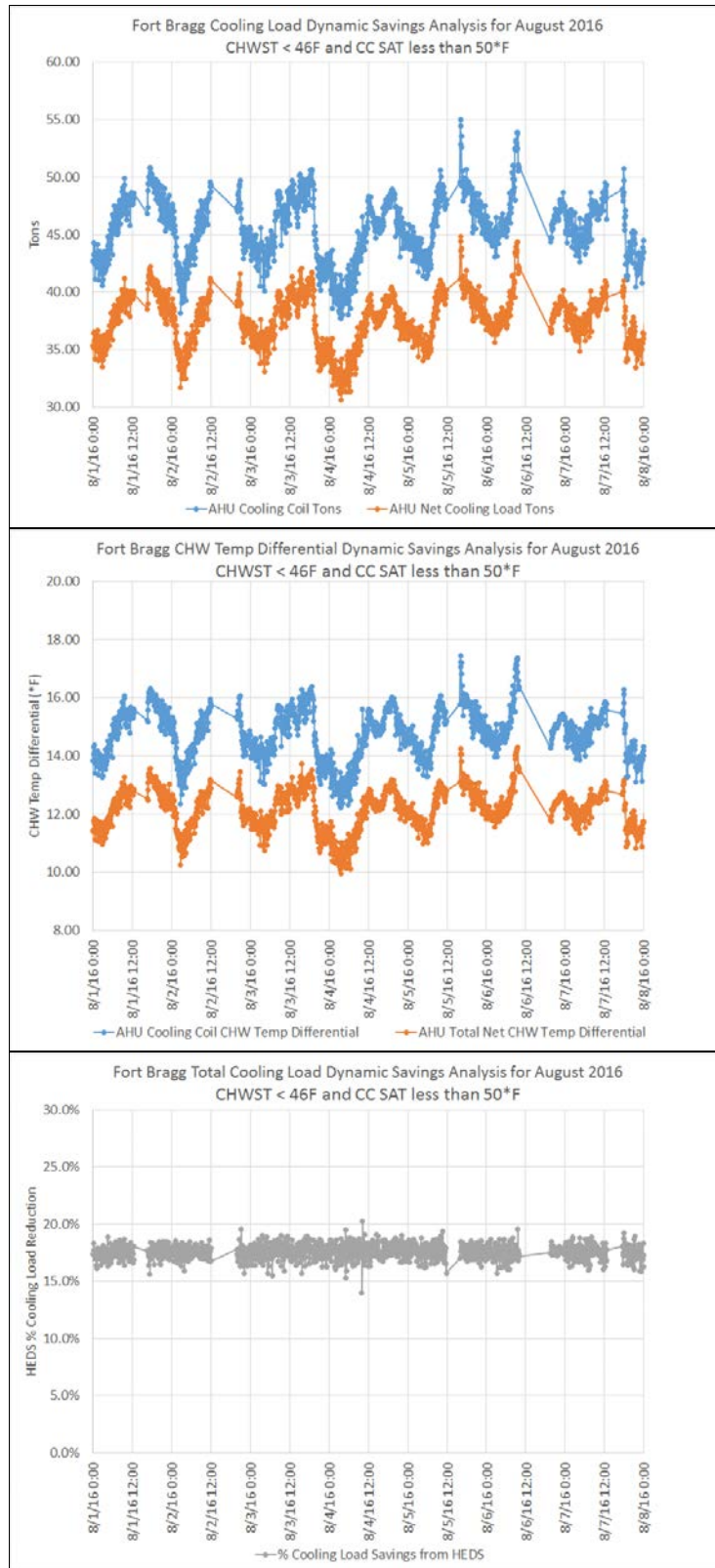


Figure 4. Dynamic HEDS Savings and Impact Analysis for the Peak Cooling Load Week of August 1, 2016.

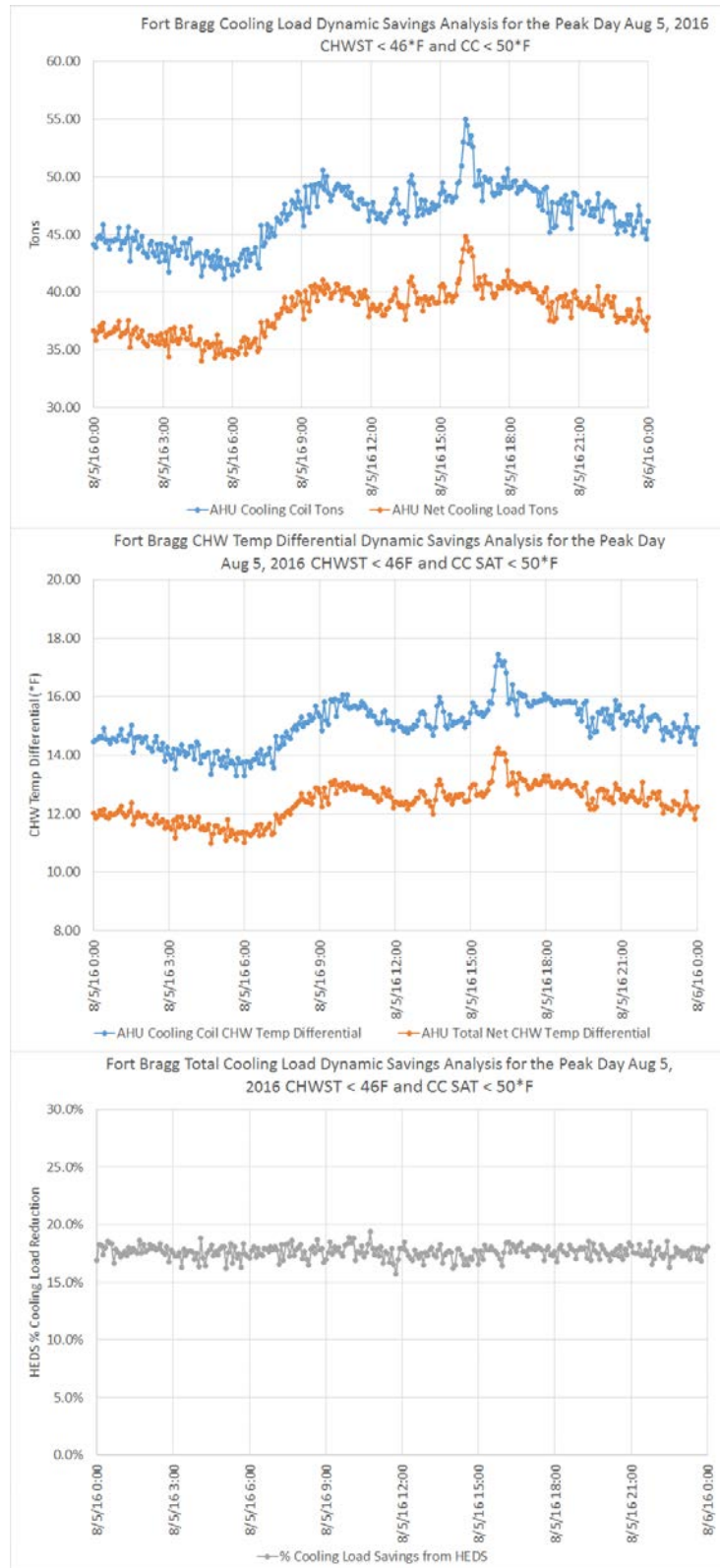


Figure 5. Dynamic HEDS Savings and Impact Analysis for the Peak Cooling Load Day of August 5, 2016.

As expected and as shown in Figure 6, the results indicate a significant dependency of the savings on the cooling coil supply air temperature when the chiller plant is meeting the leaving setpoint (less than 46 °F). As the cooling coil supply air temperature increases due to lower dehumidification loads, the leaving water temperature of the coil increases, enabling more heat recovery in the CRC.

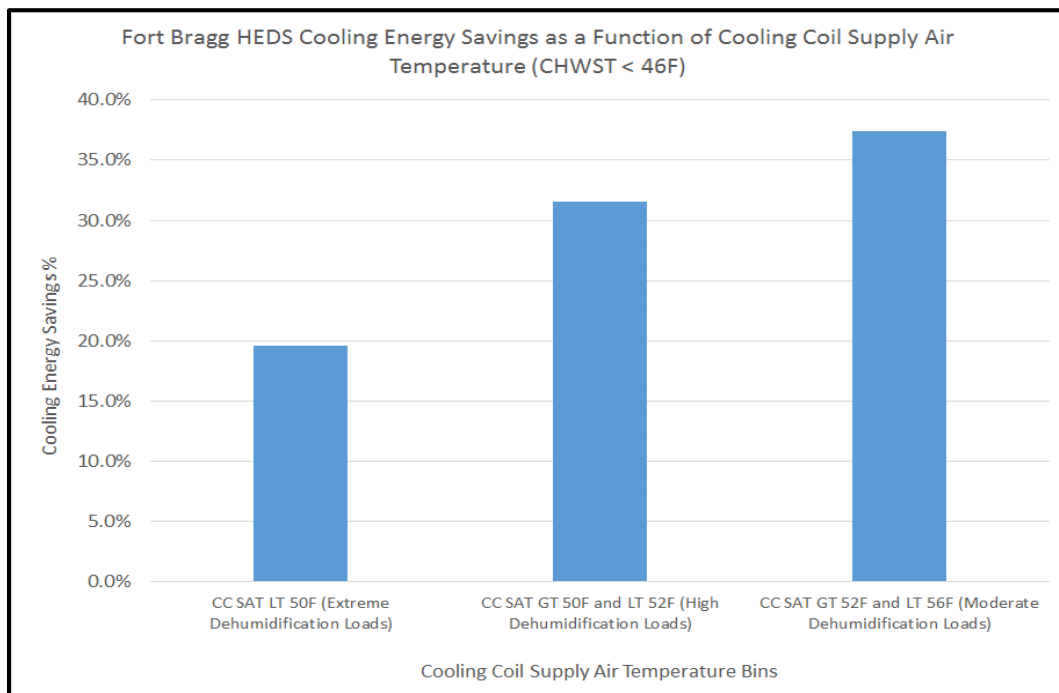


Figure 6. HEDS Cooling Load Reduction as a Function of Cooling Coil Supply Air Temp (SAT) when CHW Supply Temp is in control (less than 46 °F).

Note that the higher SAT ranges have been removed due to the limited hours of operation within the bins.

HEDS performance was tested across a range of conditions to determine a savings envelope. Very low supply air temperatures (and thus dewpoint temperatures) of less than 50 °F off the cooling coil indicate extreme dehumidification conditions typical of hospital operating rooms and clean room conditions (or extremely leaky envelopes in humid environments), while supply air temperatures off the cooling coil in the low 50s (°F) are more typical of actual field conditions.

Table 5 lists the temperature conditions across the AHU for all temperature bins. When the CHWST is in control (less than 46 °F), the results show that, even at an average cooling coil leaving dewpoint of 52 °F, which provides significant dehumidification to the space, HEDS cooling load savings increase to over 37%. In the most extreme dehumidification conditions, delivering 48 °F dewpoint air off the cooling coil, HEDS still reduced the cooling load by nearly 20%. This points to the importance of cooling coil supply air temperature resets based on space dewpoint conditions to achieve maximum energy savings.

Table 5. Fort Bragg AHU Temperatures Across the Range of Operating Conditions.

	Avg Outside Air Dewpoint Temp	Avg Space Dewpoint Temp	Avg Return Air Dewpoint Temp	Avg Mixed Air Dewpoint Temp	Avg CC Supply Dewpoint Temp	Avg CC Supply Drybulb Temp	AHU CRC Supply Drybulb Temp	AHU CRC Supply Dewpoint Temp
All Included (Filtered) Data	65.56	58.44	57.27	61.49	52.13	52.49	61.46	51.56
CHWST LT 46F (All Data)	61.51	54.87	54.19	57.88	49.67	50.18	59.97	49.06
CC SAT LT 50F	65.82	56.27	55.27	60.14	48.16	48.35	57.81	47.72
CC SAT GT 50F and LT 52F	58.39	53.39	53.35	56.35	50.66	50.99	62.83	49.77
CC SAT GT 52F and LT 56F	55.07	52.98	52.67	54.57	52.21	52.99	62.89	51.33
CC SAT GT 56F and LT 62F	43.17	44.92	45.43	45.36	44.82	58.72	69.98	44.61
CC SAT GT 62F	41.06	42.27	42.69	42.62	40.80	64.74	72.07	42.26
CHWST GT 46F and LT 50F	68.75	60.07	58.27	63.32	51.45	51.60	60.76	50.94
CC SAT LT 50F	66.33	58.13	56.11	61.31	49.20	49.36	58.32	48.96
CC SAT GT 50F and LT 52F	69.20	59.92	58.19	63.35	50.99	51.05	60.20	50.53
CC SAT GT 52F and LT 56F	69.07	60.87	59.07	63.96	52.68	52.89	62.14	52.02
CC SAT GT 56F and LT 62F	62.78	57.33	56.24	60.57	51.19	57.17	63.98	52.05
CC SAT GT 62F	58.67	55.24	54.47	52.27	52.62	64.08	64.79	49.68
CHWST GT 50F and LT 54F	71.29	63.76	61.46	66.65	55.21	55.23	63.58	54.69
CC SAT GT 50F and LT 52F	56.51	54.66	54.41	55.97	53.33	53.47	58.89	52.28
CC SAT GT 52F and LT 56F	70.46	63.15	60.79	65.82	54.55	54.58	62.91	54.07
CC SAT GT 56F and LT 62F	73.56	65.41	63.26	68.89	56.93	56.92	65.33	56.31
CC SAT GT 62F	48.73	49.42	50.61	52.09	51.22	53.37	65.94	46.81
CHWST GT 54F and LT 58F	71.21	64.79	63.39	68.17	58.87	58.93	66.20	58.37
CC SAT GT 52F and LT 56F	50.28	58.77	53.05	52.77	55.62	56.33	60.40	53.12
CC SAT GT 56F and LT 62F	71.33	64.83	63.45	68.26	58.89	58.95	66.24	58.40
CC SAT GT 62F	69.93	57.87	60.15	67.85	54.57	54.72	63.43	58.47
CHWST GT 58F and LT 62F	62.85	60.47	61.12	62.66	60.44	61.78	65.67	60.11
CC SAT GT 56F and LT 62F	61.52	59.18	59.79	61.51	59.21	60.82	64.05	59.01
CC SAT GT 62F	64.43	62.00	62.71	64.02	61.91	62.92	67.60	61.42
CHWST GT 62F and LT 66F	68.15	64.72	64.90	67.13	64.87	66.08	69.97	64.39
CC SAT GT 62F	68.15	64.72	64.90	67.15	64.87	66.08	69.97	64.40
CHWST GT 66F	71.56	68.37	68.72	71.08	68.92	69.56	73.04	68.58
CC SAT GT 62F	71.56	68.37	68.72	71.08	68.92	69.56	73.04	68.58

The elimination of the need for new reheat energy can be seen in the AHU CRC drybulb temp in Table 5. When the cooling coil leaving dewpoint averages 48 °F, the HEDS unit can deliver 58 °F drybulb air, reducing mold potential from surface condensation and ensuring a comfortable indoor environment. As loads decrease, HEDS provides additional reheat to the supply air stream to both eliminate condensation potential and track the reduced cooling loads to prevent overcooling in the space. At an average cooling coil dewpoint temperature of 52 °F and drybulb temperature of 53 °F, HEDS is able to provide 63 °F drybulb air to the space.

Peak cooling load is also reduced across the operating conditions. Peak loads were only analyzed for the steady state conditions when the CHW supply temperature from the chiller plant was in control. The results show an 18% peak demand reduction across all operating conditions. The peak is reduced by nearly 24% when the cooling coil supply air temperature is above 52 °F.

Table 6. Fort Bragg HEDS Peak Load Reduction Results when CHWST is in Control (less than 46 °F).

	Peak Cooling Coil Load (tons)	Peak Net AHU Load (tons)	Peak Load Savings (tons)	Peak Load Savings %
All Included (Filtered) Data	55.52	45.37	10.14	18.3%
CHWST LT 46F (All Data)	55.52	45.37	10.14	18.3%
CC SAT LT 50F	55.52	45.37	10.14	18.3%
CC SAT GT 50F and LT 52F	53.52	44.21	9.31	17.4%
CC SAT GT 52F and LT 56F	36.25	27.64	8.61	23.7%
CC SAT GT 56F and LT 62F	no steady state operations			

5.6.2 Tinker AFB

The results of the analysis show that the HEDS AHU significantly reduces the cooling loads and reheat energy associated with dehumidification across all operating conditions, even considering the failing chiller conditions. Additionally, HEDS was able to provide dehumidification and reheat even when the CHW supply temperature from the failing plants approached 60 °F. The HEDS system demonstrated a net 29.0% cooling load reduction across all operating conditions. When considering only those times when the chiller plant was meeting setpoint (CHW supply temperatures were less than 46 °F), the net cooling load reduction is 27.6%.

The impact of the variable air volume (VAV) system can be seen in the data compared to the Fort Bragg CAV results. The cooling coil and AHU net TD is higher across all ranges due to the lower volume of air across the coils. This results in relatively flat cooling load savings across all ranges of CHW supply and supply air temperatures at around 30%.

Figure 7 highlights the impact of the CRC on the net AHU cooling load for a peak cooling day in June followed by a part load week in the fall. Figure 7 also shows the impact on total load, AHU cooling coil and net differential CHW temperatures, and total energy savings percentage. During the peak load day in June, the average savings from HEDS is approximately 30%, with a savings at the time of coincident peak cooling load of 28.9%.

Figure 8 highlights the impact of the VAV control with the HEDS system. The resulting savings in the part load conditions stay relatively consistent with the peak load days, with average cooling load savings of just over 30%.

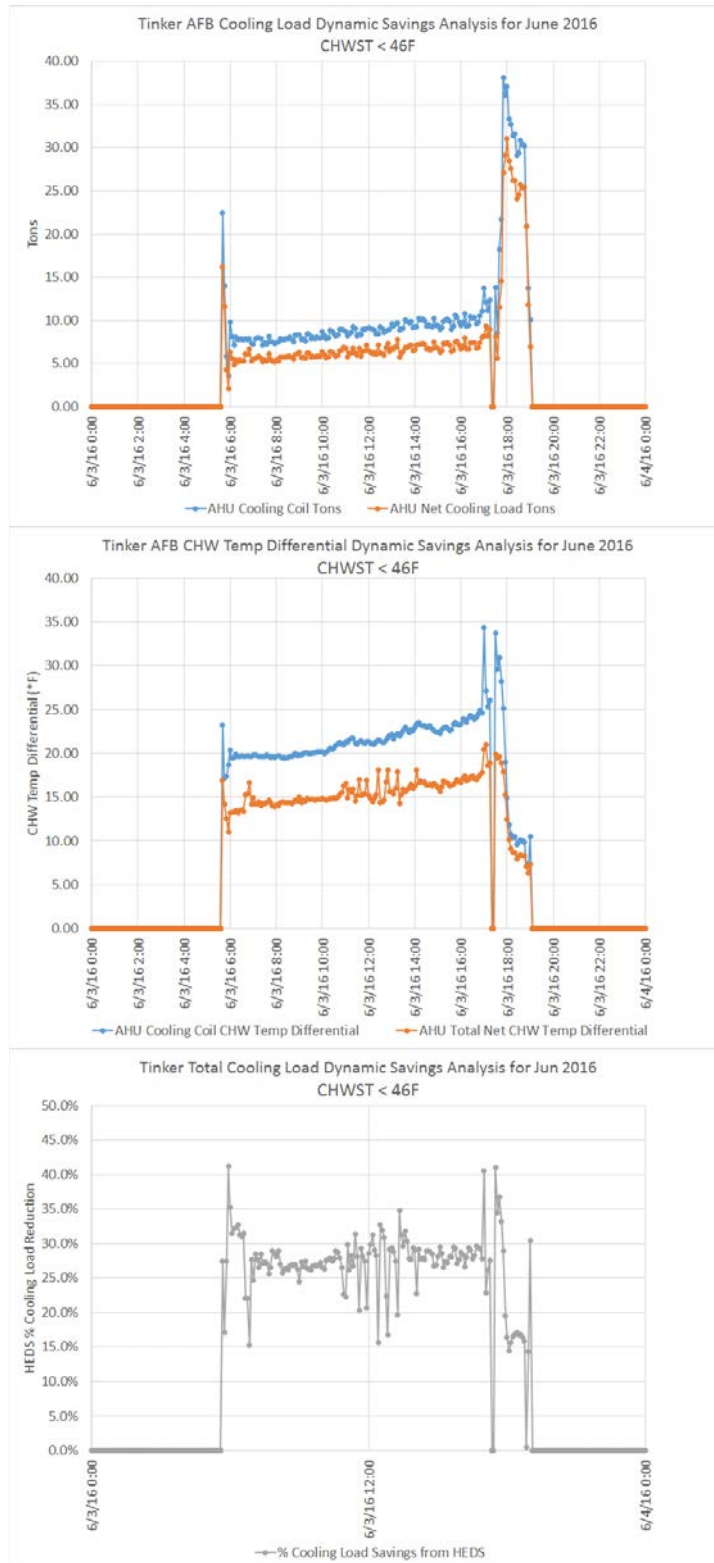


Figure 7. Tinker AFB Dynamic HEDS Savings and Impact Analysis for the Peak Cooling Load on June 3, 2016.

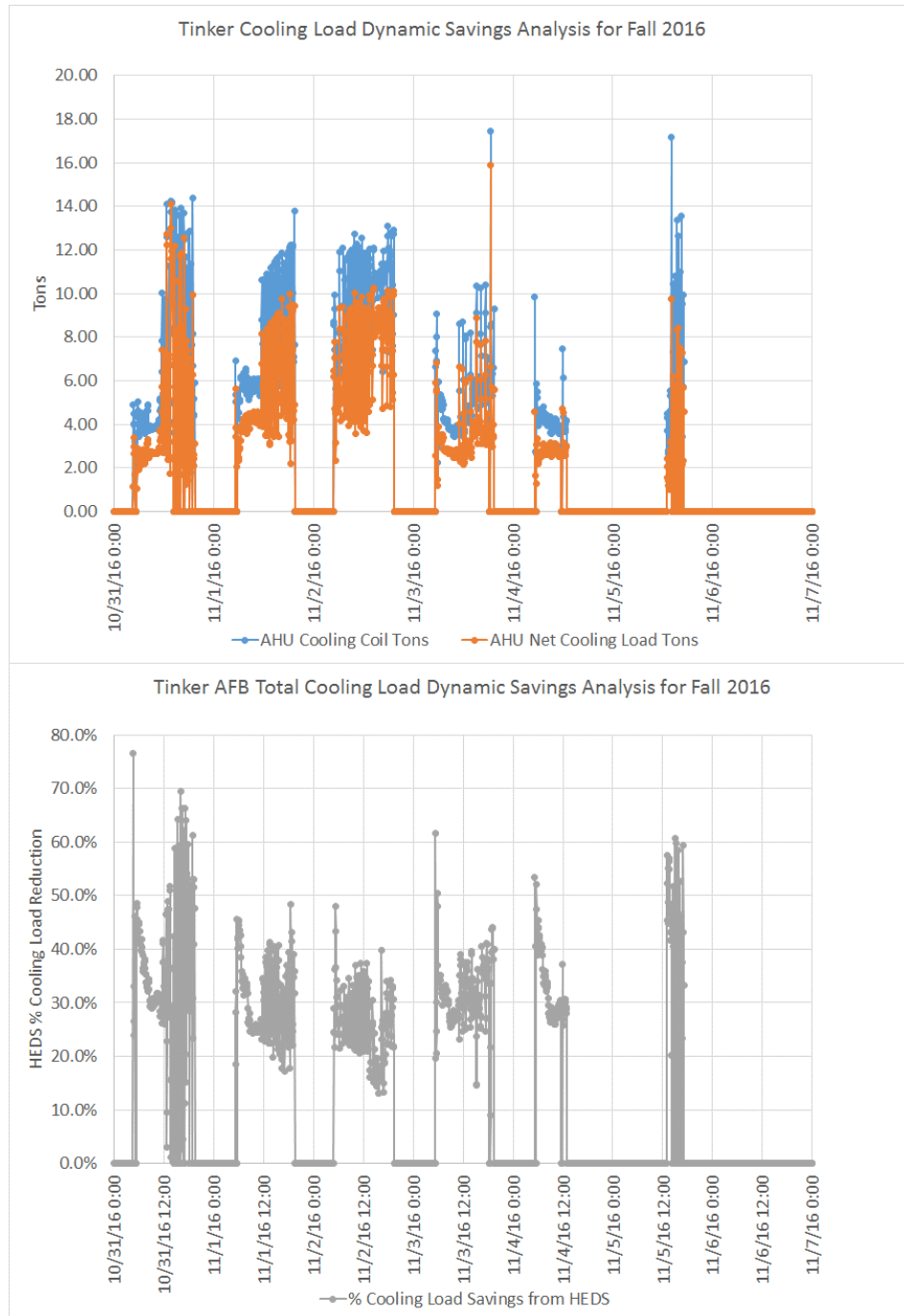


Figure 8. Tinker AFB HEDS Dynamic Savings Analysis for Part Load Days in the Fall.

As discussed previously and shown in Figure 9, the High Efficiency Dehumidification System-Variable Air Volume (HEDS-VAV) results also indicate only a modest dependency of the savings on the cooling coil supply air temperature when the chiller plant is meeting the leaving CHW supply temperature setpoint (less than 46 °F). As the cooling coil supply air temperature increases due to lower dehumidification loads, the leaving water temperature of the coil increases, enabling more heat recovery in the CRC. The warmer supply air temperatures match nicely with the reduced cooling loads.

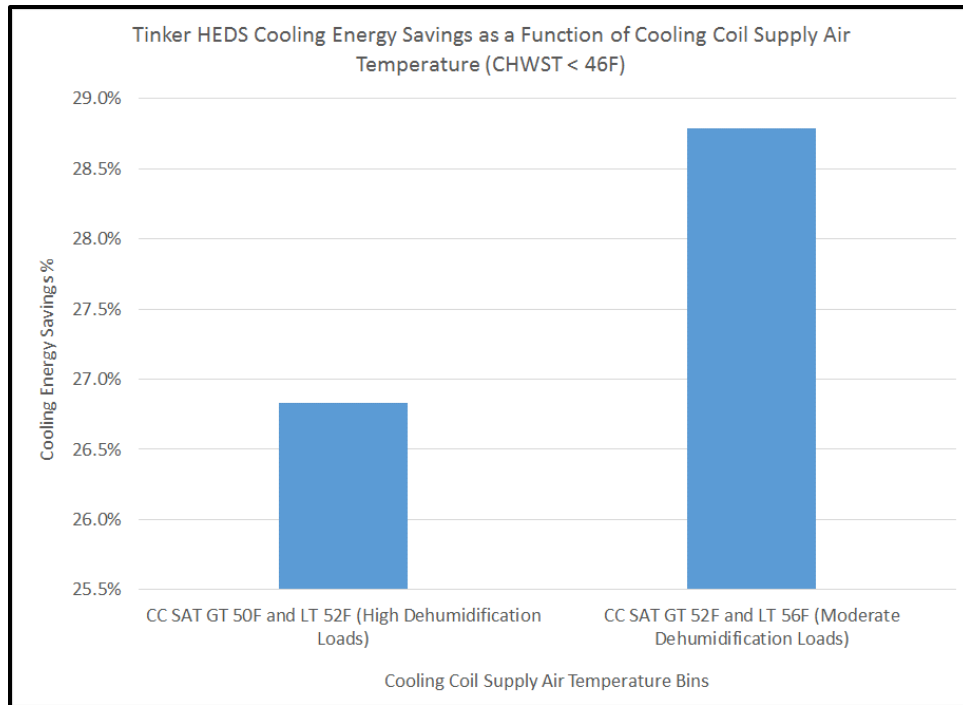


Figure 9. Tinker AFB HEDS Cooling Load Reduction as a Function of Cooling Coil SAT when the CHW Temperature is in Control (less than 46 °F).

HEDS performance was tested across a range of conditions to determine a savings envelope. Very low supply air temperatures (and thus dewpoint temperatures) less than 52 °F off the cooling coil indicate high dehumidification conditions typical of critical environments, while supply air temperatures off the cooling coil in the low to mid-50s (°F) are more typical of actual field conditions for office spaces like those served at Tinker AFB with the HEDS unit.

Table 7 lists the temperatures across the AHU for all temperature bins. With the CHW supply temperature in control (less than 46 °F), the results show that, even at an average cooling coil leaving dewpoint of 52 °F, which provides significant dehumidification to the space, HEDS cooling load savings increase to nearly 29%, very similar to the Fort Bragg savings under the same conditions. In the higher dehumidification conditions, in which 50 °F dewpoint air was delivered off the cooling coil, HEDS still reduced the cooling load by nearly 27%.

Table 7. Tinker AFB Average AHU Temperatures Across the Range of Operating Conditions.

	Total HEDS Savings % (saved ton-hrs / CC ton-hrs)	Avg Outside Air Dewpoint Temp	Avg Return Air Dewpoint Temp	Avg Mixed Air Dewpoint Temp	Avg CC Supply Drybulb Temp	Avg CC Supply Dewpoint Temp	AHU CRC Supply Drybulb Temp	AHU CRC Supply Dewpoint Temp
All Included (Filtered) Data	29.0%	63.88	54.62	60.41	54.85	53.87	66.39	53.91
CHWST LT 46F (All Data)	27.6%	61.33	51.57	56.88	52.65	51.76	63.73	51.76
CC SAT LT 50F	20.5%	61.80	51.03	58.79	47.19	44.71	56.16	44.74
CC SAT GT 50F and LT 52F	26.7%	62.47	52.10	59.86	51.32	50.48	64.76	50.61
CC SAT GT 52F and LT 56F	28.8%	61.15	51.44	56.23	52.90	52.15	63.64	52.12
CC SAT GT 56F and LT 62F	20.9%	57.55	53.56	56.86	57.52	52.41	63.39	52.43
CC SAT GT 62F	10.9%	56.96	54.37	57.32	71.12	55.77	73.37	55.49
CHWST GT 46F and LT 50F	30.3%	63.74	53.28	60.00	52.75	52.09	65.59	52.00
CC SAT LT 50F	21.1%	65.15	53.62	60.32	49.41	51.88	57.93	48.13
CC SAT GT 50F and LT 52F	33.7%	65.46	52.83	60.33	51.44	51.26	65.49	50.97
CC SAT GT 52F and LT 56F	28.9%	63.13	53.43	59.89	53.13	52.37	65.75	52.35
CC SAT GT 56F and LT 62F	27.7%	59.17	54.10	58.12	56.88	53.95	66.12	55.52
CC SAT GT 62F	5.9%	56.36	54.48	65.30	68.48	52.82	72.98	59.47
CHWST GT 50F and LT 54F	27.2%	65.30	55.79	62.99	55.62	54.83	68.58	54.90
CC SAT GT 50F and LT 52F	28.5%	61.05	55.71	59.08	55.26	54.85	63.34	50.66
CC SAT GT 52F and LT 56F	26.9%	65.60	55.53	63.32	55.37	54.54	69.11	54.35
CC SAT GT 56F and LT 62F	29.1%	64.84	56.41	62.41	56.21	55.49	67.68	56.27
CC SAT GT 62F	7.9%	64.98	56.42	64.44	56.09	55.52	66.70	61.92
CHWST GT 54F and LT 58F	31.9%	67.73	59.55	64.61	59.38	58.64	70.19	59.19
CC SAT GT 52F and LT 56F	23.3%	68.50	58.74	64.52	56.45	55.93	65.60	54.68
CC SAT GT 56F and LT 62F	32.8%	67.75	59.54	64.62	59.49	58.74	70.42	59.25
CC SAT GT 62F	23.5%	67.04	60.15	64.70	58.95	58.23	68.54	61.31
CHWST GT 58F and LT 62F	30.3%	66.53	61.54	64.13	61.98	60.77	70.31	61.33
CC SAT GT 56F and LT 62F	27.7%	63.82	59.33	61.94	61.04	58.82	67.25	58.60
CC SAT GT 62F	31.0%	67.55	62.15	64.96	62.24	61.31	71.16	62.37
CHWST GT 62F and LT 66F	27.0%	66.49	61.96	64.91	62.90	61.14	71.13	63.22
CC SAT GT 62F	26.9%	66.46	62.01	65.04	62.96	61.19	71.15	63.30
CHWST GT 66F	16.3%	66.44	61.55	66.74	60.83	59.44	69.25	66.33
CC SAT GT 62F	16.3%	66.44	61.55	66.74	60.83	59.44	69.25	66.33

Similar to the Fort Bragg results, the AHU CRC drybulb temperatures in Table 7 show the elimination of the need for new reheat energy. When the cooling coil leaving dewpoint temp averages 50 °F, the HEDS unit can deliver 65 °F drybulb air to the space, reducing mold potential from surface condensation and ensuring a comfortable indoor environment.

Peak cooling load is also reduced across the operating conditions. Peak loads were only analyzed for the steady state conditions where the CHW supply temperature from the chiller plant was in control. The results show a 29% peak demand reduction during the peak cooling period on June 3, 2016.

Table 8. Tinker AFB HEDS Peak Load Reduction Results when CHWST is in Control (less than 46 °F).

	Peak Cooling Coil Load (tons)	Peak Net AHU Load (tons)	Peak Load Savings (tons)	Peak Load Savings %
All Included (Filtered) Data	38.13	27.11	11.02	28.90%
CHWST LT 46F (All Data)	38.13	27.11	11.02	28.90%
CC SAT LT 50F	no steady state operations			
CC SAT GT 50F and LT 52F	no steady state operations			
CC SAT GT 52F and LT 56F	38.13	27.11	11.02	28.90%
CC SAT GT 56F and LT 62F	no steady state operations			
CC SAT GT 62F	no steady state operations			

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6.0 PERFORMANCE ASSESSMENT

6.1 SAVINGS ANALYSIS METHODOLOGY

Although extensive performance monitoring equipment for both airside and waterside have been installed on the AHUs, due to the nature of the HEDS system, very few data points are required to determine the performance of the system compared to a typical AHU with reheat or “baseline” condition. This is a result of the fact that the cooling load is an independent, uncontrolled variable in the analysis since the cooling load is determined by the space and ambient conditions. Specifically, the leaving AHU cooling coil temperature is controlled to maintain primarily the space dewpoint and secondarily, the space temperature within setpoints.¹ Therefore, the baseline cooling load can be considered to be the load on the cooling coil in the HEDS unit, and the savings due to the CRC are determined by the cooling coil load minus the net delivered AHU cooling load to the chiller plant, as described below:

$$\text{Baseline Cooling Load (tons)} = (\text{CC CHWST} - \text{CC Chilled Water Return Temperature (CHWRT)}) * \text{Belimo Energy Valve (BEV) CHW Flow (GPM)} / 24$$

$$\text{Net AHU Cooling Load (tons)} = (\text{CC CHWST} - \text{Common CHWRT}) * \text{BEV CHW Flow (GPM)} / 24$$

$$\text{HEDS Cooling Load Savings (tons)} = \text{Baseline Cooling Load} - \text{Net AHU Cooling Load.}$$

Note that for the purposes of this demonstration, fan energy savings associated with the HEDS low pressure drop coils have not been considered. To determine net electricity savings from the cooling load savings, the efficiency of the central plant must be considered, as shown below:

$$\text{HEDS Electricity Savings (kW)} = \text{HEDS Cooling Load Savings (tons)} * \text{Chiller Plant kW/ton}$$

Chiller plant efficiencies, considering all parasitic components, can typically range from 0.5 – 2.5 kW/ton, depending on the equipment, configuration, controls, and geographic location.

Reheat energy savings calculations depend on the reheat energy source. For electric reheat, the cooling load savings can be converted directly to electricity with no losses, as shown below:

$$\text{HEDS Electric Reheat Savings (kW)} = \text{HEDS Cooling Load Savings (tons)} * 3.517 \text{ kW/ton}$$

For boiler systems, the delivered efficiency of the hot water or steam must be considered, as shown below:

$$\text{HEDS Boiler Reheat Savings (therms)} = \text{HEDS Cooling Load Savings (tons)} * 0.12 \text{ therms/ton} / \text{Boiler System Efficiency}$$

Typical delivered boiler system efficiencies, considering the boiler efficiency, cycling losses, and distribution losses, can range from 30 to 85% depending on the system design, controls, delivery medium (steam, high temp hot water, hot water), and load factors.

¹ The control system resets the cooling coil leaving temperature based on the dewpoint temperature in the space. As the space dewpoint temperature rises, the cooling coil leaving temperature setpoint drops to provide increased dehumidification. As the space dewpoint falls, the cooling coil leaving temperature is increased to reduce unnecessary dehumidification.

6.2 COOLING LOAD SAVINGS VS. COOLING ENERGY SAVINGS

One important distinction to make is that the cooling load savings % is a much smaller figure than the actual cooling energy % savings that will show up at the utility meter.

For 24/7 loads, most chiller plants are equipped with VFDs on pumps and cooling towers, and many 15-year-old or less chiller plants also have one or more variable frequency drive high efficiency chillers. Due to Affinity Laws, equipment that is controlled by a VFD saves energy in a non-linear fashion, meaning a small speed reduction due to a load reduction equates to a much higher energy % reduction. For example, CHW pumps with VFDs operate with an Affinity Law power relationship of approximately 2.5, so if the cooling load goes down by 20%, the pump energy requirement equals $(1-0.2)^{2.5} = 57\%$, a savings of 43%. Condenser water pumps and cooling tower fan motors typically unload to the power of 2, while a VFD chiller may unload to the power of 1.5, so it can be seen that cooling energy savings can be significantly greater than cooling load % savings.

Additionally, for administrative use facilities that are supposed to have 5 days/week, 12 hr/day HVAC occupancy schedules, but that may be running 24/7 due to inadequate and undersized HVAC AHUs, the switch to a HEDS based system can reduce AHU and chiller plant runtime by 90+ hrs/week, in addition to the cooling load reduction. This equates to an approximate 50% run time reduction, which provides not only substantial energy savings, but significant maintenance savings as well.

6.3 DATA DESCRIPTION

The performance data spans from April 1 through November 9, 2016 for the analysis included in this report. During this range, at Fort Bragg trend data points were collected for 98.8% of the available time period, as some data gaps exist due to equipment outages and upgrades. During this range, at Tinker AFB, trend data points were collected for 86.6% of the available time period, as some data gaps exist due to trend collection issues, equipment outages, and upgrades.

7.0 COST ASSESSMENT

This chapter describes the cost components of the HEDS system and summarizes cost-benefit assessments and lifecycle cost analyses.

7.1 COST MODEL

HEDS components are very similar to those of a typical AHU designed for dehumidification duty. As such, cost estimating for the HEDS system is very similar to cost estimating for typical dehumidification-duty AHU deployments in either new construction or retrofit scenarios. One key difference is that the HEDS unit will typically cost 2 to 3 times that of a typical AHU, given the large coil sections, low face velocities, and enhanced controls.

The table below shows a simple cost model for cost estimating support for HEDS projects. Note that the actual equipment and installation costs will vary significantly due to a number of factors, including:

- Requirements for marine environments and coil coatings,
- Requirements for special duty such as low dewpoint applications, redundancy, etc.,
- Location of the unit (roof, mechanical room, etc.) and whether the unit will be installed as separate components or broken up to fit the unit into an existing space, and
- Existing availability of CHW distribution.

Table 9. Cost Elements of HEDS.

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Equipment capital costs	Estimates made based on component costs for demonstration, includes all HEDS AHU components and controls	\$10/CFM
Installation costs	Labor and material required to install, including curbs/pads, electrical connections, etc.	\$6/CFM
Consumables	Air Filters are the only consumables, typical of a normal AHU; data not tracked	Same as typical AHU, no additional cost
Facility operational costs	Reduction in energy required vs. baseline data	See Performance Results
Maintenance	Frequency of required maintenance Labor and material per maintenance action Data not tracked	Same as typical AHU, no additional cost
Hardware lifetime	Estimate based on components degradation during demonstration	25 years based on typical AHU lifetimes
Operator training	Estimate of training costs	Included in equipment costs, no additional cost

A description of each cost element can be found below.

7.2 EQUIPMENT CAPITAL COSTS

The capital cost for the HEDS AHU is typically the largest cost element of a HEDS project. This cost includes all of the elements typical of a dehumidification-duty AHU, including supply fan(s), return or exhaust fan(s) (if required), preheat coil (if required), cooling coil, CRC, control valves, RHC or strip heating (if required), instrumentation, controls, filter and access sections, and dampers. The cost data presented are based on multiple cost estimates from Trane for units of similar size to those deployed at the test sites. The test site unit costs could not be used directly due to the enhanced instrumentation that was installed for testing purposes, which significantly increased first costs. Future equipment costs can be explored with approved HEDS AHU providers on a case-by-case basis, as is typical of the AHU industry.

This assessment uses a comparative metric for the unit costing of \$ per CFM, which is the cost per cubic feet per minute of airflow that the unit is capable of delivering. The cost per CFM is an industry standard used to approximate equipment and installation costs. Smaller CFM equipment typically has a higher \$/CFM for both equipment and installation than larger CFM equipment due to fixed costs for controls, instrumentation, design, commissioning, and the like. The cost estimates included above are for an approximate 10,000 CFM HEDS AHU.

7.3 INSTALLATION COSTS

Installation costs are the other key cost element of a HEDS installation. These costs typically include all elements of the physical installation, including demolition of existing units (as needed), new pads or curbs to accept the new HEDS unit, electrical and controls connections, ductwork connections, startup, balancing, and commissioning. Cost estimates were developed based on typical AHU installations on-grade. Note that many factors will influence installation costs in the field and can be estimated based on typical AHU estimating techniques (assuming a HEDS AHU is roughly twice the size of a standard AHU with 500 ft/minute face velocity).

7.4 CONSUMABLES

The only consumables for the HEDS units are air filters, as is typical of any AHU. Typically, air filters in HEDS units will last longer than in traditional AHUs due to lower face velocities, which reduce the total pressure drops experienced by the filters for a given loading. There may be more filters in a HEDS unit however, so it is expected that the net costs of filters will be neutral. At the time of the report, the filters had not yet been changed, but it is expected that the filter cost may be neutral, or slightly less expensive overall than a normal AHU.

7.5 FACILITY OPERATIONAL COSTS

As discussed throughout this report, energy costs will be significantly reduced for HEDS units compared to almost any other dehumidification technology. Energy cost savings will vary based on multiple factors, including utility rates, CHW plant efficiencies, and reheat plant type and efficiency. The total energy savings will also depend on what baseline system HEDS is being compared with. For this report, HEDS is compared against a typical dehumidification reheat AHU with a cooling coil and RHC provided by hot water or electric strip heat.

7.6 MAINTENANCE

HEDS AHUs have components typical of any CHW AHU (as described above). Therefore, maintenance requirements are similar to those of any other AHU. At the time of this writing, there had been no maintenance required on the HEDS AHU. The HEDS AHUs use direct drive, rather than belt drive, fans, and motors so the annual maintenance costs should be slightly lower than those of a normal AHU.

7.7 HARDWARE LIFETIME

Again, since HEDS is so similar to a typical AHU, lifetimes are expected to be similar to any other CHW AHU. The Building Owners and Managers Association International (BOMA) Preventive Maintenance Guidebook (Schoen, 2010) uses the following average equipment lifetimes for AHU equipment, which will be similar for HEDS units based on application:

- Severe Duty or 100% Outdoor Air Units: 20 years
- Packaged Medium Duty: 25 years
- Built-up Heavy Duty: 30 years.

7.8 OPERATOR TRAINING

Operator training is an important component of any robust operating and maintenance program. Although HEDS units are very similar to traditional CHW AHUs in components and layout, there are specialized control functions that are included and that require training to support ongoing performance. This training is included with the purchase of the HEDS units based on existing manufacturer licensing agreements, so currently the training has no upfront cost.

7.9 COST DRIVERS

Many of the key cost drivers for HEDS deployment were discussed in the Cost Elements section above. There are infinite combinations of requirements for any AHU selection that will affect total system cost. Two key elements are crucial to how the net cost of a HEDS project should be considered.

First, it is critical to consider what the baseline equipment selection is or would have been, and to consider the incremental cost (or savings) associated with the HEDS unit deployment. For example, for a building project with a simple CHW reheat AHU as the baseline, the cost of the baseline system may be \$3/CFM compared with a HEDS unit at \$10/CFM. Installation costs between the two units are likely similar, when the larger footprint and weight of the HEDS installation compared with this baseline is offset by the smaller pipe diameters and pump flow rates required to serve the HEDS unit. Assuming a \$1/CFM higher installation cost, the net cost of the HEDS installation would be \$8/CFM, typically resulting in a very fast payback when the energy savings are considered compared with a traditional reheat AHU baseline.

Now consider the case where new sources of reheat are not allowable by code (such as governed by ASHRAE 90.1). In this case, the baseline system may be a DX unit with hot gas reheat, which eliminates the need for new reheat sources. The first cost for this DX unit may be \$9/CFM, compared with a HEDS unit at \$10/CFM. Installation costs may be slightly higher for the HEDS unit for CHW

pipng, but this may be offset by the increased electrical distribution costs and higher weight of the DX unit. Even assuming the HEDS unit installation cost is on net \$2/CFM higher, the net cost of the HEDS unit is only \$3/CFM. In this case, HEDS does not provide reheat energy savings compared with the baseline but does provide significant cooling energy savings given the higher efficiency of a CHW plant compared to air-cooled DX equipment and the reduced load of the HEDS unit from the cooling recovery process for the reheat.

Another key element to consider in HEDS installations is the space constraints of the space for the unit. In certain applications, particularly retrofit scenarios, there simply may not be adequate space for a HEDS unit to fit properly, given its size compared to tradition dehumidification-reheat solutions. However, in situations where a reheat AHU is not allowed (as discussed above, for example where ASHRAE 90.1 energy code is in effect), a like for like retrofit would not be possible anyway, requiring additional engineering to develop solutions to enable other technologies like HEDS to be deployed to eliminate the use of new energy for reheat. These scenarios can greatly increase the overall installation cost, but this cost would be seen in both the baseline and HEDS scenarios.

7.10 COST ANALYSIS AND COMPARISON

This section gives an overview of the cost comparisons and lifecycle analyses for both test sites.

Two capital cost values were used in the analysis. A retrofit cost value of \$16/CFM was used; a retrofit scenario assumes the project bears the entire cost of the HEDS unit and installation, such as equipment replacement before EUL. An incremental cost value of \$8/CFM was also used. Incremental cost values would apply in new construction, major renovation, and equipment EUL situations; incremental cost values also represent retrofit cases where the AHU can be rebuilt in place without entire unit replacement. Note that, in new construction applications, HEDS can significantly reduce other infrastructure costs due to chiller and piping downsizing, cooling tower downsizing, etc. due to the cooling load reductions; these cost savings were not included in the lifecycle cost analysis presented here but should be considered where possible.

Note that where energy codes require that simultaneous heating and cooling cannot be used for RH control (such as ASHRAE 90.1), the incremental cost of HEDS would approach \$0/CFM, and could even have significant cost savings, depending on the comparative technology used as baseline.

Figures 10 to 13 highlight the lifecycle performance across a range of scenarios for Fort Bragg performance results. For the purposes of this report, savings for the temperature bin for high dehumidification loads (cooling coil supply air temperature less than 50 °F) and at mid-level electricity and natural gas are presented. Other temperatures bins have very similar results. Results are shown as a 20-year savings to investment ratio (SIR), where the total savings over 20 years are divided by the project costs.

The results show SIRs above 1 across all scenarios, reaching over 4 for the retrofit applications and over 9 for new construction, EUL, and major renovation applications. Even at the low-level electricity and natural gas rates, SIRs are above 1 in almost all scenarios and reach as high as 2.7.

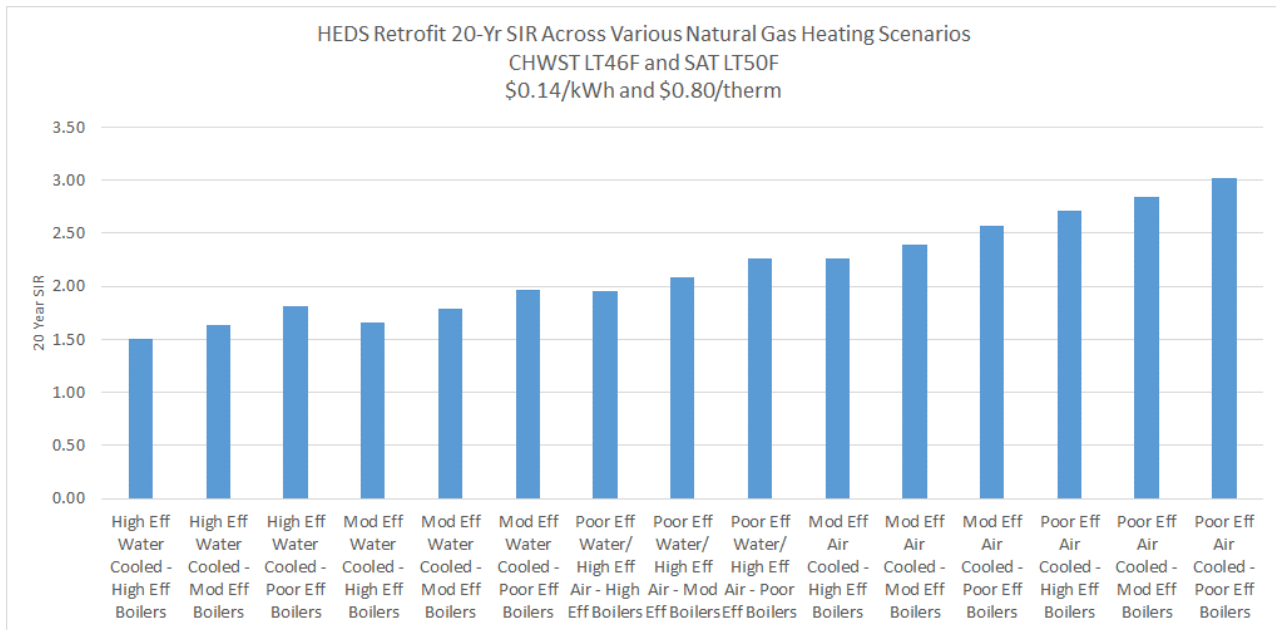


Figure 10. HEDS Retrofit, 20-yr SIR Across Various Natural Gas Heating Scenarios.
(CHWST LT46F and SAT LT50F, \$0.14/kWh and \$0.80/therm)

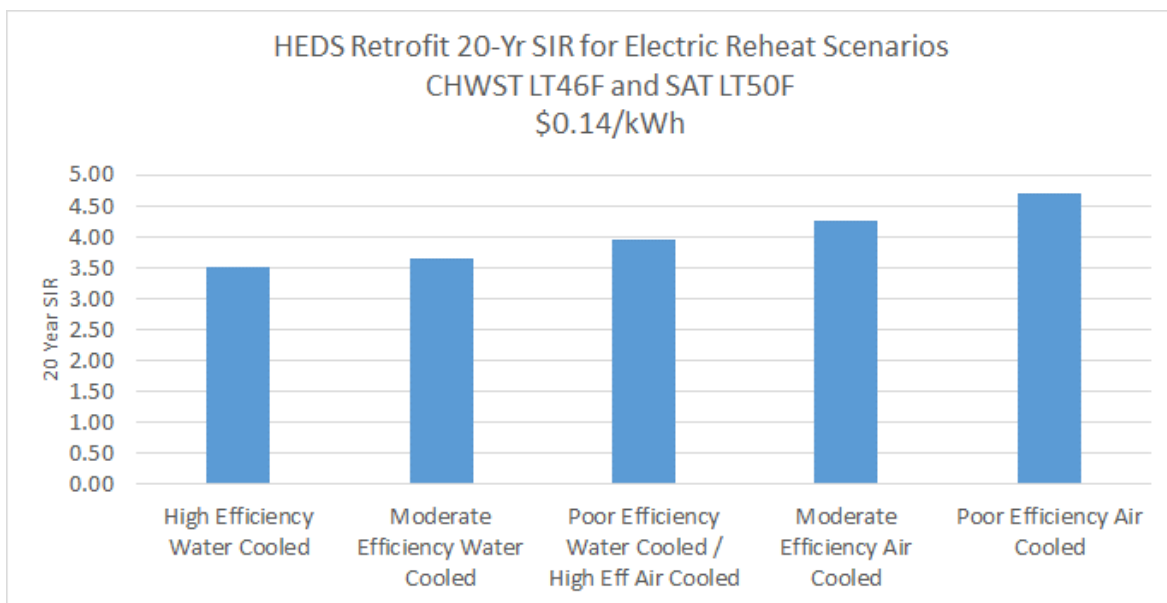


Figure 11. HEDS Retrofit, 20-yr SIR for Electric Reheat Heating Scenarios
(CHWST <46 °F and SAT <50 °F, \$0.14/kWh)

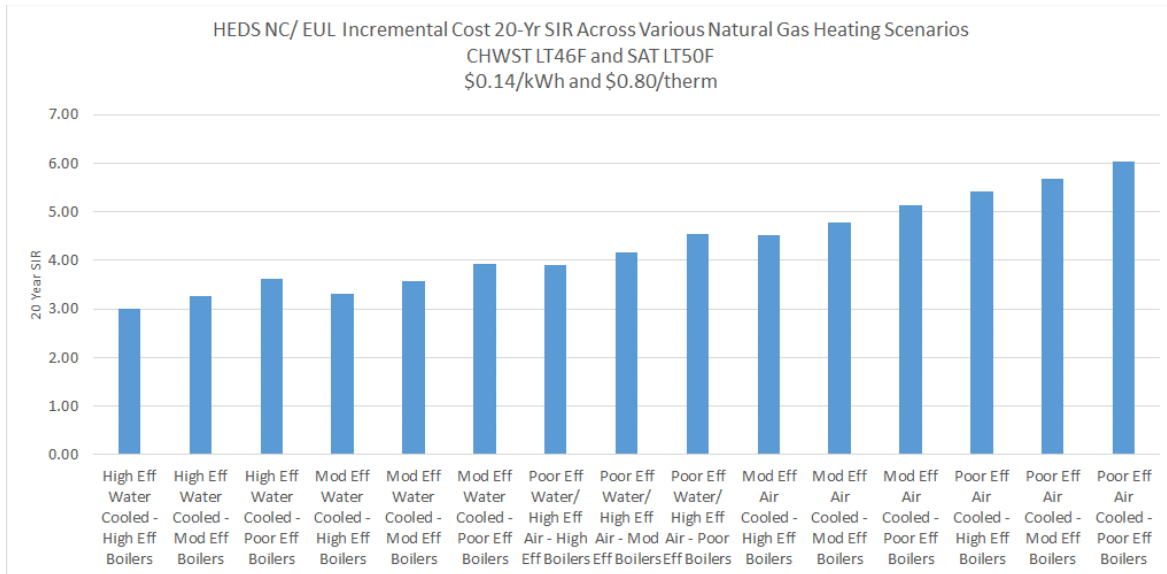


Figure 12. HEDS NC/EUL Incremental Cost, 20-yr SIR Across Various Natural Gas Heating Scenarios.
(CHWST LT46F and SAT LT50F, \$0.14/kWh and \$0.80/therm)

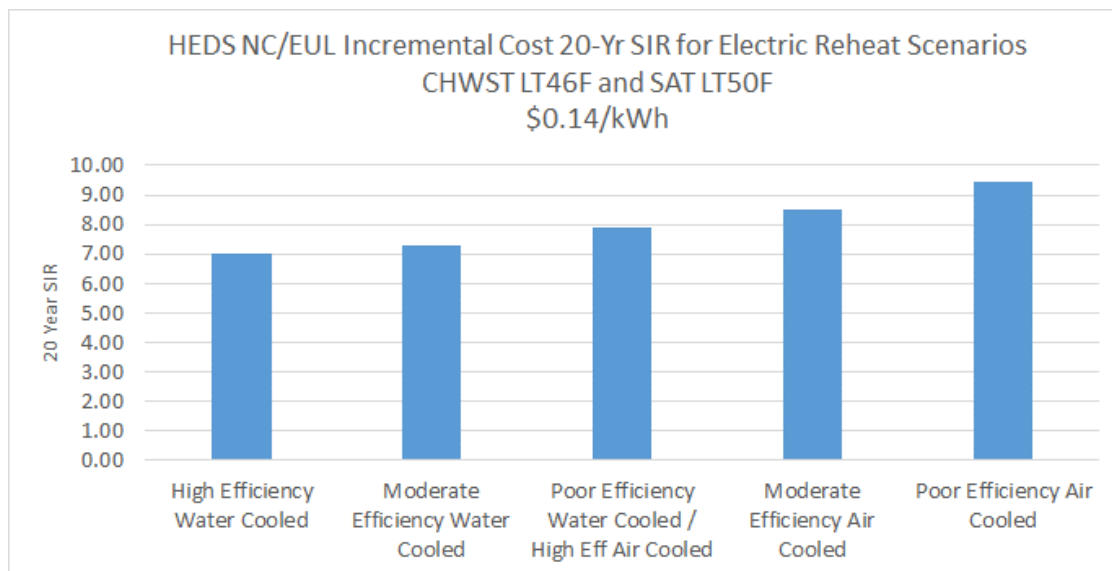


Figure 13. HEDS NC/EUL Incremental Cost, 20-yr SIR for Electric Reheat Scenarios.
(CHWST LT46F and SAT LT50F, \$0.14/kWh)

Figures 14 to 17 highlight the lifecycle performance across a range of scenarios for Tinker AFB performance results. Results are shown as a 20-year SIR, where the total savings over 20 years are divided by the project costs. The results show SIRs above 1 across all scenarios, reaching nearly 3 for the retrofit applications and nearly 6 for new construction, EUL, and major renovation applications. Generally, lifecycle cost performance is lower for the Tinker installation due to lower overall cooling loads associated with the VAV system in an administrative building versus the constant volume system in a kitchen at Fort Bragg.

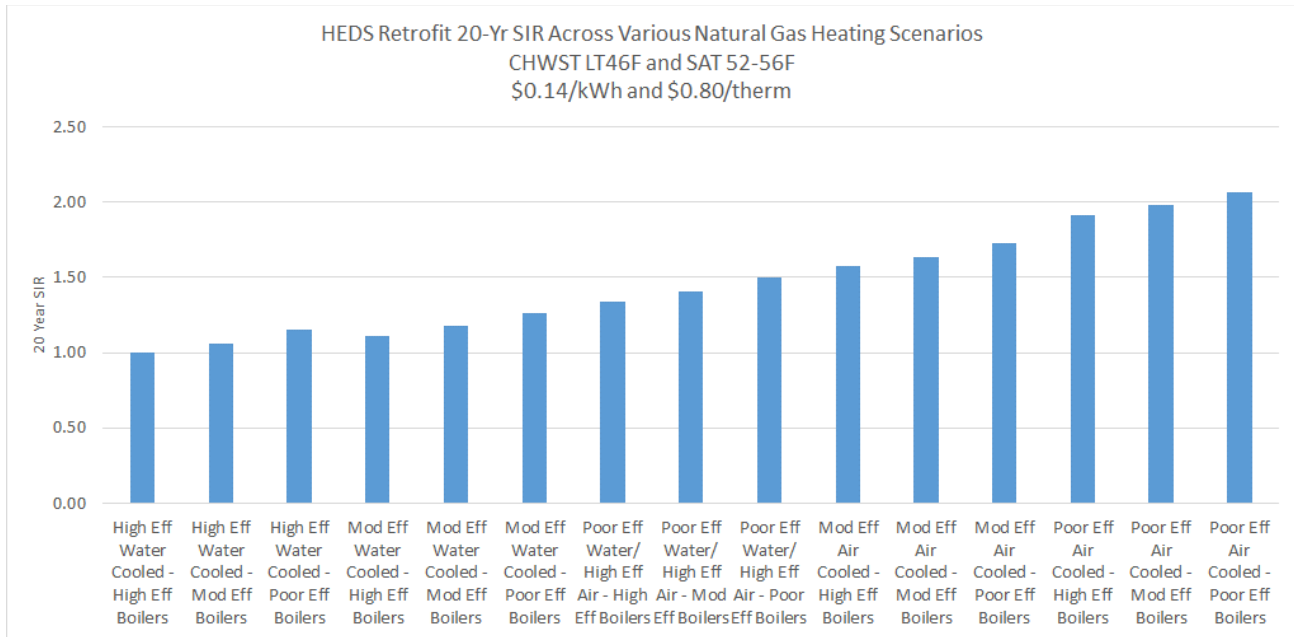


Figure 14. HEDS Retrofit 20-yr SIR Across Various Natural Gas Heating Scenarios.
(CHWST LT46F and SAT <52-56 °F, \$0.14/kWh and \$0.80/therm).

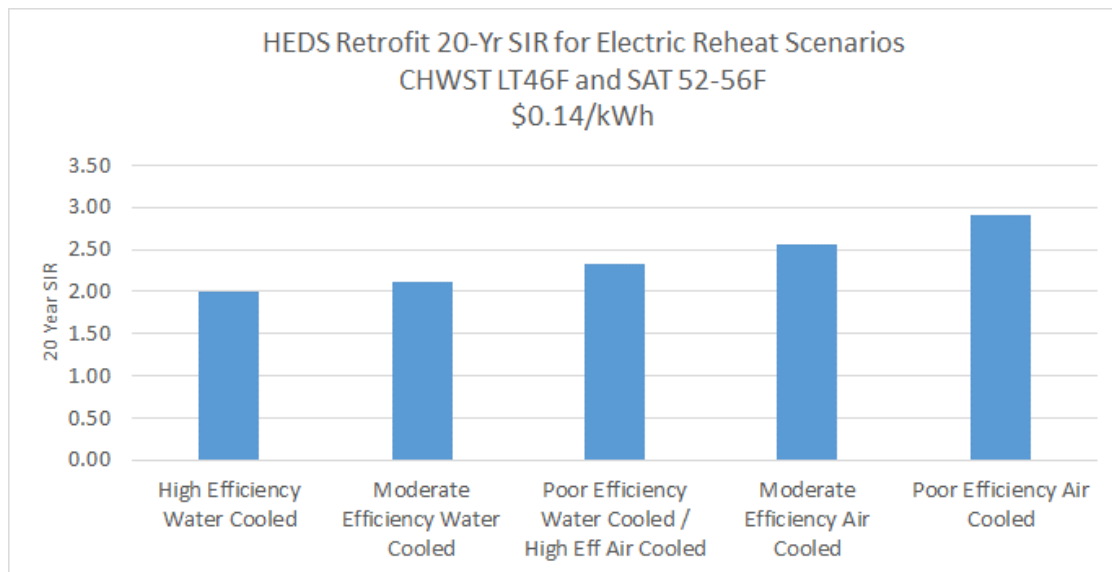


Figure 15. HEDS Retrofit, 20-yr SIR for Electric Reheat Scenarios.
(CHWST LT46F and SAT <52 to 56F, \$0.14/kWh)

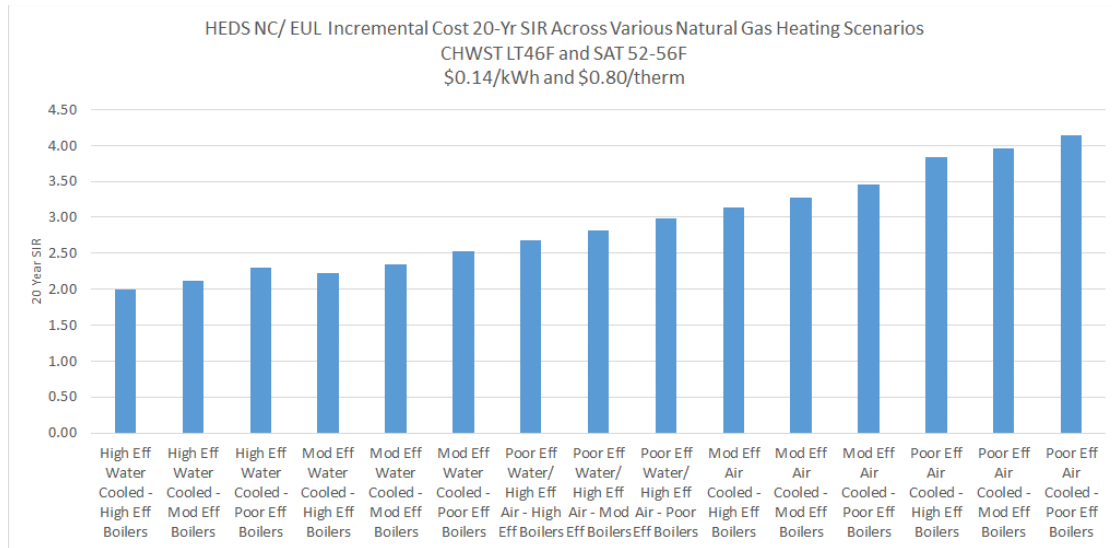


Figure 16. HEDS NC/EUL Incremental Cost, 20-yr SIR Across Various Natural Gas Heating Scenarios.

(CHWST LT46F and SAT 52 to 56 °F, \$0.14/kWh and \$0.80/therm)

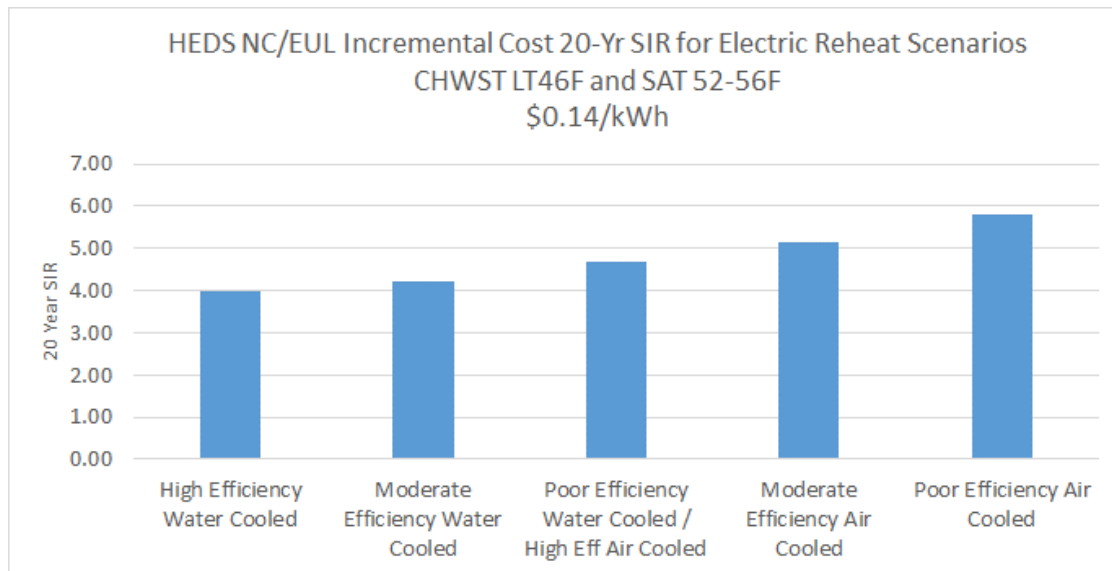


Figure 17. HEDS NC/EUL Incremental Cost, 20-yr SIR for Electric Reheat Scenarios.

(CHWST LT46F and SAT 52 to 56F, \$0.14/kWh)

8.0 IMPLEMENTATION ISSUES

8.1 PROCUREMENT ISSUES

Currently, HEDS units are only available under license with one manufacturer, which can limit procurement options. The current plan is to evaluate several different manufacturers to determine their ability to meet the quality and support levels that we expect, and to license the technology to at least two more manufacturers. Given that few AHUs are commercial off-the-shelf items (they are mostly built to order), HEDS units will need to use the same market channels of mechanical product vendors, installers, and AHU manufacturers to achieve market scale. This will require deep engineering support from the vendor networks, which requires training, education, and experience with HEDS systems.

8.2 POTENTIAL BARRIERS TO ACCEPTANCE

One major barrier to acceptance is market skepticism with new technologies that claim such high savings levels. We are consistently running into situations where there is a great potential project, or projects, but the engineer is able to stop the projects by asking “where have you done HEDS in a facility similar to mine, in a climate similar to mine?” More technology demonstration projects in different applications and third-party validation is needed to substantiate the savings claims. Additionally, there is often significant pushback within the industry that requires demonstrated performance in similar applications, which slows the adoption of HEDS and any new and potentially market-disruptive technologies.

Insufficient resources to properly operate and maintain HVAC systems on DoD installations is an ongoing concern for public works staff. With limited funding and/or understaffed personnel available to accommodate their existing building stock and associated equipment, installation directorates of public works are often reluctant, unwilling, or unable to work with new technologies that they are unfamiliar with.

The simplicity of the HEDS design and operating strategy should help to overcome public works staff’s reluctance to embrace a new technology. Documenting and publicizing the implementation of the HEDS Environmental Security Technology Certification Program (ESTCP) project at the two demonstration sites should help to encourage further adoption of the technology. Users of the new technology need to be confident it will consistently and reliably save energy, reduce biological growth, reduce lifecycle costs, and improve the comfort of the buildings’ occupants over the long term, without increasing their manpower and funding requirements.

8.3 ASHRAE 90.1 PRESCRIPTIVE ENERGY CODE REQUIREMENTS

The latest version of ASHRAE 90.1 prescriptive energy codes explicitly disallows any form of simultaneous cooling and heating or reheating of air for RH control, if the heat or reheat is not from a reclaimed or solar-thermal source. HEDS is one of the few HVAC system designs that is ASHRAE 90.1 prescriptive energy code compliant regarding RH control, because it uses reclaimed energy for the reheat energy source.

The vast majority of HVAC systems in Federal facilities do not comply with the latest versions of ASHRAE 90.1 (90.1-2007, -2010, -2013, and -2016) with respect to RH control. HEDS may be the most cost-effective solution for the DoD and also for the tens of thousands of Federal office buildings, embassies and consulates in humid climates to reduce energy and water waste; to improve comfort, health, and wellness; and to comply with ASHRAE.

When HVAC systems need to be replaced, repaired or upgraded, HEDS may be the only cost-effective solution to provide ASHRAE 90.1 compliance across a broad range of HVAC system sizes and types, given some of the following attributes:

- HEDS can be a cost effective ASHRAE 90.1 RH control solution that can be applied for systems ranging from 100 CFM (i.e., barracks), to 1,000,000 + CFM (i.e., aircraft paint hangars, known as corrosion control facilities) and all sizes in between, and
- HEDS is the only ASHRAE 90.1 compliant solution that will physically fit in many of the existing AHU, Dedicated Outdoor Air System (DOAS), RTU, Packaged Terminal Air Conditioner (PTAC), and FCU locations.
- HEDS maintenance requirements are lower than any other RH control option.

8.4 LESSONS LEARNED

In addition to validating the key performance objectives, several key lessons were gleaned from the demonstration project, as described below.

- CHW plant performance can significantly impact HEDS performance, but to a much lesser extent than non-HEDS AHUs. This has to do with two primary factors: the heat transfer surface area is 400 to 600% greater for a HEDS based cooling coil than it is for a typical non-HEDS cooling coil, and also, the amount of time that the air spends in contact with the heat transfer finned area is approximately 4 to 6 times longer for the HEDS unit than for the non-HEDS unit. Both test sites experienced chiller plant failures and capacity limitations that resulted in very high and unstable CHW temperature control. Since dehumidification is limited by the CHW temperature entering the AHU, this impacts any AHU's ability to provide dehumidification. However, even under these conditions, HEDS was able to provide more dehumidification and reduce total cooling loads compared with a traditional dehumidification-reheat AHU. At 60 °F ± CHW supply temperatures, the HEDS units were still providing significant amounts of dehumidification, as indicated by a steady flow of condensate pouring out of the HEDS AHU, and slight, random condensate dripping out of the non-HEDS units. During these times the areas served by the HEDS AHUs were still comfortable, when the non-HEDS unit areas were hot, muggy, and uncomfortable. Even at 60 °F + CHW supply temperatures, HEDS was able to reduce the cooling loads by 15%+, allowing this saved capacity to be delivered to the non-HEDS AHU.
- Accessibility of operating staff and maintenance data on DoD sites can be challenging – Given the significant turnover and lack of documentation of maintenance practices, quantifying non-energy impacts of systems demonstrations can be difficult on military bases.

During startup and operator training, the HVAC mechanics commented on a few different items: They found the direct drive fans to be a significant benefit over the typically installed AHUs that use belt drives, as belt slippage and maintenance issues are typically pain-points for them; they saw the large, low face velocity air filters as a benefit, inasmuch as they rarely have time to change air filters as often as they would like to change them; and they saw the HEDS design as common-sense-simple. “We’ve always hated to have to run the boilers in the summer, it just seems stupid to run a boiler when it is 85 °F outside, but we know they have to run or we get a ton of cold calls and mold starts growing.” “This is simple and just makes sense.” “This will save us a lot of boiler maintenance and cold calls in the summer.”

- Other system operating constraints may limit overall HEDS impact – at Fort Bragg, the three other AHUs serving the DFAC had capacity limitations and operating issues that limited the ability to realize additional savings from reducing the runtimes of the building. If all units had been replaced with HEDS units, it is expected that the operating times of the equipment could be better aligned with the actual occupied hours of the facility, instead of running 24x7 as is currently required. For the Tinker AFB demonstration site, the runtimes were able to be reduced for the HEDS unit compared to the previous unit operation.

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9.0 REFERENCES

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